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SEVENTY-THIRD

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1918

BY

EDWARD C. PICKERING

CAMBRIDGE, MASS.
PUBLISHED BY THE UNIVERSITY
1919

THE OBSERVATORY

To the President of the University: —

Sir, — Two astronomical events have excited much popular interest during the past year. They furnish excellent examples of the policy of the Observatory — coöperation and thrifty management. The first of these events was the appearance of the New Star in the constellation Aquila, first seen on June 8, 1918, the second, the Total Eclipse of the Sun, the same day. The Observatory at once sent out cablegrams and letters, requesting observations of the brightness of the New Star, not only to Europe and America, but also to our correspondents in Africa, Japan, Australia, New Zealand, and the Sandwich Islands. As a result, including a few published observations, we have received 2094 estimates from 90 observers. Measures have been obtained on every night since its first appearance, and on many days when it was below the horizon in America. Thus, for the first time, a nearly continuous watch has been kept of a celestial object by a chain of observers extending around the Earth. Photographs taken here show its existence before its discovery, from May 22, 1888, to June 3, 1918. During this time it underwent slight variations in light. Three photographs on June 7, 1918, showed it of the sixth magnitude, about one hundred times its original brightness, and during the next day it again increased about two hundred times.

Eclipse expeditions are expensive with a prospect, if cloudy, that no results will be obtained. Even if clear, the result seldom justifies the cost. Accordingly, no expedition was sent at the expense of the Observatory. As, however, Miss Cannon desired to see the eclipse, a wooden photometer was furnished her, but, owing to clouds, results of importance were not secured.

Excellent results are being obtained from the two astronomical Fellowships. Some of these results are published in H.A. **84**, Nos. **1**, **2**, and **3**, and much more material is nearly ready for the printer. The Charles S. Hinchman Fellowship has been established by the generous gift of Mrs. Hinchman, and is now filled by Miss Mary D. Applegate. Miss Dorothy W. Block is the Edward C. Pickering Fellow.

The liberal coöperation of Professor Plaskett, mentioned in my last report, promises results of the greatest value. Excellent photographs taken with the 72-inch Telescope have been sent here,

which show that they will serve to determine the brightness of the faintest stars. We can thus materially extend the usefulness of this great instrument.

Henry Draper Memorial

The Henry Draper Catalogue has made good progress under the supervision of Miss Cannon. It has been printed and distributed as far as $4^h\,00^m$ in right ascension; it is in type as far as $9^h\,00^m$; the copy is completed as far as $12^h\,00^m$; the remainder is written and is nearly ready for the printer. To complete it, the " Remarks " must be written, and the photographic magnitudes determined.

Numerous requests for the results of this Catalogue have been received from astronomers in all the principal countries of Europe and the United States. The number of spectra sent in advance of publication exceeds 37,000. It will save time in supplying this material if the positions of the stars for 1900, or their identifications in the Durchmusterung, are given.

Numerous photographs of the spectra of Nova Monocerotis and of Nova Aquilae, No. 3, have been taken with the 8-inch Draper Telescope and 24-inch Reflector. With the latter instrument, plates stained with pinacyanol have been used, showing the Hα line.

The photographic observations at Cambridge have continued under the supervision of Professor King. The number of plates taken with the 24-inch Reflector is 179, making 2,109, in all; with the 16-inch Metcalf Telescope, 1,694, making 15,323, in all; with the 10-inch Metcalf Telescope, 1,501, making 2,513, in all; with the 8-inch Draper Telescope, 193, making 39,487, in all; with the 1-inch Cooke Anastigmat, 1,330, making 20,550, in all; with the 0.5-inch Voigtländer, 1,328, making 17,602, in all. The total number of plates exposed was 8,052, of which 7,155 were photographs of the stars. Adding to these the photographs taken in Arequipa, the total number of plates taken since 1884 is approximately 273,472. Among them, 173 good plates for determining the position of the Moon, 5 of Uranus, and 5 of Neptune have been obtained. Besides these, 897 enlargements, copies, etc., have been taken, making 29,743, in all. Measures of the light of the sky have been continued, especially during the period of coal shortage, when many street lights were extinguished. To save coal, the main building of the Observatory was closed for several weeks.

Boyden Department

The Arequipa Station has continued under the charge of Mr. L. C. Blanchard, who has carried on a large amount of work without assistance. The principal work of the Bache Telescope has been taking the photographs in series needed to determine the photographic magnitudes of southern stars. This instrument has now been replaced by the 10-inch Metcalf Telescope, which gives much better images and a larger field. It is expected that results of great value will thus be obtained. The number of plates taken with the 24-inch Bruce Telescope is 86, making 11,808, in all; with the 10-inch Metcalf, 219, making 2,732, in all; with the 8-inch Bache, 1,445, making 53,082, in all; with the 1-inch Cooke Anastigmat, 837, making 14,466, in all. The total number of photographs of the stars is 3,355.

The Mandeville Station of the Harvard Observatory has continued under the direction of Professor W. H. Pickering. A considerable portion of the time of the 11-inch Draper Refractor was given to the study of Mars, in connection with the work of the other members of the International Association, and a reasonable non-artificial explanation of the formation and seasonal shifting of the more prominent canals has been found. Three reports, Nos. 18, 19, and 20 have been issued, and a fourth is now under preparation. An investigation of the shifting bright areas in the lunar crater Plinius, and of the changing visibility of the minute craterlets in Plato has been made. Further measures of the colors of the stars and planets have been secured, and a further study made of the telescopic indications of the approach of distant hurricanes.

The zenith equatorial for the rapid determination of the seeing has been completed, and it is found that the instrument can be opened, a zenith star found, the quality of the seeing determined, and the instrument closed, without undue haste, in an interval of three minutes. This instrument is particularly useful in connection with planetary observations, where a high quality of seeing is demanded. A study of Daylight Seeing at different hours for solar observations has also been made with this instrument. Numerous observations of the Gegenschein and Zodiacal Band have been secured. A number of observations of the brightness and color of Nova Aquilae were made, and its maximum brightness determined under rather favorable conditions, owing to the possibility of comparing it with our recollections of Canopus, which was only slightly fainter, and which rises well above the southern horizon in the winter season.

Blue Hill Meteorological Observatory

The observational and routine work has been carried on during the year, and a series of thirty-two consecutive years of data made available through the published summaries in H.A. **83**, Part **2**. Actual and sensible temperature, pressure expressed in units of force, humidity, wind direction and velocity, night cloudiness, rainfall, snowfall, evaporation, and phenological phenomena showing the progress of the season have been recorded without interruption. No special papers were published although some investigations on wind as a factor in evaporation were carried on.

A summary of the mean monthly and yearly temperatures expressed in the Kelvin kilograde scale was prepared and published for the purpose of showing the saving in composition and the gain in accuracy as compared with the Fahrenheit scale. This is of importance in the presentation of climatological data; and in this, as in other matters, Blue Hill Observatory is playing the rôle of pioneer. It is essential that in all upper air work a scale of this nature be used owing to the frequency of occurrence of temperatures below the freezing point of water. In the Kelvin kilograde scale the zero is the absolute zero and the freezing point of water under standard pressure 1000. No degree symbols are used, that symbol being reserved for angular measures.

Much educational work was accomplished for the benefit of the United States Navy in the way of training young officers in Aerography. Fifty ensigns have taken the course. Professor McAdie was absent on foreign service for about six months.

Photographic Magnitudes

The determination of photographic magnitudes on the International Scale has continued under the supervision of Miss Leavitt. Series of twelve plates each, two being on the North Pole, are taken, and a diffraction grating over the objective gives an independent measure of the magnitude. The number of series taken with the 10-inch Metcalf Telescope is 44 with blue light, and 24 with yellow light. The corresponding numbers taken at Arequipa, with the 8-inch Bache Telescope, are 87 with blue and 34 with yellow light. The principal work now in progress with these photographs is the determination of the magnitudes of sequences for the regions adopted as standards by the Committee of the International Chart of the Sky, for Kapteyn's Selected Areas and Special Areas, and for a large number of regions near clusters,

novae, variables, and other objects of special interest. About 72,000 estimates have been made of the brightness of stars in standard sequences and catalogues, and 18,000 of twenty-six novae and variable stars.

Variable Stars

Professor Bailey has completed his study of four of the globular clusters, ω Centauri, and Messier 3, 5, and 15. A beginning has been made of the study of the thirteen other clusters which are known to contain variable stars. The total number of distinctively globular clusters is 77, and it appears probable that the list is essentially complete, as no others have been found during the last half century. Unfortunately, 44 of these are south of $-25°$, and only 33 are north. About fifty photographs of each cluster are desired for a satisfactory study of the variables. With a large reflector, suitable photographs can be obtained in five or ten minutes. The erection of such an instrument in the southern hemisphere is an urgent need. Its work during a single night would provide material for months of study.

With the polarizing photometers attached to the 15-inch Equatorial, Mr. Leon Campbell has made 9,352 settings, including 2,752 on the asteroid Eunomia, 400 on Iris, 1,152 on Uranus, 1,488 on the new star in Aquila, and 258 on the satellites of Jupiter on five nights while undergoing eclipse.

By friendly coöperation, the observation of variable stars has been greatly extended. Mr. C. L. Brook has sent us important results of observations by the British Astronomical Association. The work has been extended to the variables when faint by Professor S. A. Mitchell, Director of the McCormick Observatory, and Professor H. C. Wilson, Director of the Goodsell Observatory. Excellent results for southern stars, hitherto much neglected, have been obtained through Mr. J. F. Skjellerup from the Cape Astronomical Society, Mr. Baldwin, Director of the Melbourne Observatory, and Professor Dawson, of the La Plata Observatory. The total number of observations is 2,589. The American Association of Variable Star Observers has contributed 16,113 observations. In all, 22,478 observations have been made or received here, distributed as follows: —

W. J. Luyten, 4,289; L. Campbell, 1,744; H. A. Bancroft, Jr., 1,637; C. Y. McAteer, 1,433; T. C. H. Bouton, 1,330; J. F. Skjellerup, 974; B. H. Dawson, 830; G. B. Lacchini, 804; Ed. de Perrot, 743; M. A. Hawes, 708; A. W. Long, 615; McCormick Observatory, 592; C. T. Whitehorn, 558; E. H. Vogelenzang,

SEVENTY-FOURTH

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THE OBSERVATORY

To the President of the University: —

Sir, — The Astronomical Observatory has suffered an irreparable loss during the past year through the death, on February 3, of Edward Charles Pickering, for forty-two years its Director. Under his control, the Observatory became "preëminent in America, and in certain fields leader of the world," and he came to be regarded as "The Dean of American Astronomy." Outlines of his life and work have been published in many scientific journals.

Notwithstanding the energy and promptness with which observations were prepared for publication under his superintendence, a large amount of material remains, which is practically ready for the printer, but which cannot be published as rapidly as is desirable for want of funds. The demand for the six remaining volumes of the Henry Draper Catalogue is insistent, and provision should soon be made for three additional volumes of Kapteyn's "Selected Areas." Several other volumes of miscellaneous astronomical researches and meteorological observations are also ready for printing. The prompt publication of all this material is necessary in order to complete worthily the great life work of the late Director. This would require, owing to the increased cost of printing, a sum of about fifteen thousand dollars, in addition to the regular income of the Observatory.

An attempt has been made during the year to render more systematic and effective the photographic survey of the Milky Way for the discovery of Novae and other interesting objects. The plan includes the prompt examination of photographs of small scale made both at Cambridge and Arequipa, in order to establish definitely, through a limited period, perhaps, the number of such new stars above a certain magnitude. Their discovery hitherto has been largely a matter of chance, and in general confined to naked-eye stars. The present investigation extends to the ninth magnitude. New stars, so far as known, occur only in or near the Milky Way. Two new stars have been thus discovered, one by Miss Joan C. Mackie and one by Miss Ida E. Woods, in addition to a number of new variables.

The two astronomical fellowships for women have been filled by Miss Dorothy W. Block and Miss Mary D. Applegate. Toward the end of the year, Miss Block was called to a position at the Yerkes Observatory, and the fellowship was assigned to Miss Antonia C. Maury, who is engaged in a study of the spectroscopic binaries discovered at this Observatory.

Dr. Joel H. Metcalf, during his summer vacation at South Hero, Vermont, made a remarkable record by the independent discovery of three comets within two days, with a telescope made by himself. One of these comets had been observed several days earlier in Europe, and another is probably Brorsen's Comet of 1847, whose rediscovery at this time is an event of unusual interest.

Henry Draper Memorial

The publication of the Henry Draper Catalogue has made steady progress. Three volumes have now been issued. Of the remaining six, one is in type and the other volumes can be made ready for the printer as rapidly as the necessary funds are available. Miss Cannon, in addition to supervising the publication of this Catalogue, has completed investigations regarding the spectrum of Nova Aquilae, No. 3, stars of composite spectra, and spectra of the variable stars of long period. She is also engaged in a study of the spectra of red stars.

The photographic observations at Cambridge remain under the direction of Professor King. The total number of plates exposed at Cambridge was 5,166, of which 4,700 were photographs of the stars. The number of successful plates made with the 16-inch Metcalf Telescope for the position of the Moon was 79.

Measures for the determination of the light of the sky have been continued, using both blue and yellow light.

The discussion of the work already done in obtaining photovisual magnitudes of stars and planets by the out-of-focus method has been completed. The paper includes the determination of the color index, not only of the bright planets but also of Nova Aquilae, No. 3. Similar work has been begun on a more extended list.

A new method has been devised of converting sidereal to Greenwich mean time, expressed in thousandths of a day, corresponding to the middle time of exposure. By this method, the speed of reduction is more than doubled.

Boyden Department

The Arequipa Station has been under the charge of Mr. F. E. Hinkley, who has been assisted by Señor J. E. Muñiz. The 10-inch Metcalf Telescope has been employed in making the plates in blue and yellow light necessary for the extension of photographic and photovisual magnitudes to the southern stars. Considerable work has also been accomplished with the Bruce 24-inch and the Boyden 13-inch Telescopes, as well as with smaller instruments. The whole number of plates made at Arequipa during the year was 3,308.

The Mandeville Station in Jamaica has continued under the direction of Professor W. H. Pickering, who reports that the regular observations of the ellipticities and position angles of the elongated disks of Jupiter's four larger satellites have been maintained. Special studies have been made of the seasonal changes occurring in the lunar crater Eratosthenes, consisting mainly of the development of the various fields and canals, and the shifting location of the latter. An investigation of the numerous small snow fields lying near Conon has been undertaken, and the usual dates of appearance and disappearance of each have been determined.

While the evidence is against the duplication of the canals of Mars, and each of the observers this past year has expressed the view that the appearance was simply an illusion, yet oddly enough certain of the canals occurring in the snow craters of the Moon are either really double, or else appear to be so by contrast with the snow. The widest and most clearly marked parallel pair so far detected lie in a craterlet on the rim of Posidonius, its breadth being 0″.6 or about 3,600 feet. It is only double near the full, and its duplication is without doubt the most difficult test for definition yet investigated upon the Moon.

Only one Report was issued this year on the observations of the International Associated Observers of Mars. As many as twenty-five well-known canals were seen by at least six observers, and eighty-three were seen by as many as two. Some of the latter were very difficult, and only temporary. The chief ones have been found to shift over the surface, in a manner agreeing with predictions previously published. The positions of twenty-six lakes were determined, and confirmed by at least two observers.

Blue Hill Meteorological Observatory

The observational and routine work of the Observatory has been carried on without a break. Records covering a period of thirty-four years are now available for the elements of pressure, temperature, humidity, precipitation, sunshine, day and night cloudiness, wind direction and velocity. The data for the civil year 1918 have been published in the usual form in H.A. **83**, Part **3**. There were no special papers published, but material is now available for memoirs on cloud measurements, humidity, and wind velocities at flying levels.

Several new instruments have been devised, one in particular, an absolute humidity recorder which should prove a valuable instrument in astronomical observatories, since it gives a continuous record of actual and sensible temperatures and both relative and absolute humidities. Such instruments in the dome of an observatory might help to throw light on some of the questions connected with good seeing.

Photographic Magnitudes

This work has continued under the direction of Miss Leavitt. The 16-inch Metcalf Telescope continues to be used for plates, taken in series, which give the means of comparing all parts of the sky, visible in Cambridge, with the North Pole. The 10-inch Metcalf Telescope has been used in Arequipa for similar work, replacing the 8-inch Bache Telescope. All parts of the southern sky are compared with Harvard Standard Regions having centres at the declination $+15°$. Both instruments are equipped with diffraction gratings, giving an independent measure of the scale of magnitudes. The measurement of sequences on series plates has been practically completed for the fifty Harvard Standard Regions with blue and with yellow light, for the 252 Selected and Special Areas of Kapteyn with blue light, for the 216 selected regions in overlapping zones of the Carte du Ciel with blue light, and for many special objects with blue and with yellow light. Measures for catalogues of stars brighter than the eleventh magnitude in regions four degrees square have been completed for each of the thirty-six Harvard Standard Regions north of the equator. Two plates with blue and two with yellow light are measured for each region. These will give photographic and photovisual magnitudes for about 11,000 stars. A beginning has been made on simi-

lar catalogues for regions south of the equator. The determination of the magnitudes of comparison stars for variables and the study of their light curves continue to be important features of the work of this department. Many requests for information concerning new or suspected variables have been answered. Owing to conditions brought about by the war, the number of assistants has been reduced, and the volume of observations is somewhat smaller than that reported last year. They include about 50,000 measures of the brightness of stars in sequences and catalogues, about 24,000 estimates of the brightness of Novae and variables, and about 3,500 measures of the brightness of asteroids. A card catalogue which will contain information regarding every star whose magnitude is determined from the photographs is in preparation. The whole number of stars whose magnitudes have been derived from two or more blue plates is now in the neighborhood of 30,000.

Variable Stars

Systematic visual observations of variable stars have been continued by Mr. Leon Campbell, who also has supervised the observations received from the members of the American Association of Variable Star Observers, and others in foreign countries. Professor Mitchell, Director of the McCormick Observatory, Professor Wilson, of the Goodsell Observatory, and Professor Parkhurst, of the Yerkes Observatory, by their coöperation with large telescopes, have furnished much needed magnitudes of faint variables near minimum. The light curves derived from all these observations are more complete than ever before.

Mr. Campbell has attempted, also, to follow the variables with the 15-inch Telescope, when too faint to be observed with smaller instruments, or when other observations were lacking. With the photometers attached to the 12-inch and 15-inch Telescopes, he has secured 8,474 settings, of which 3,680 were of Algol and short period variables, 1,872 of the minor planets for evidence of variability, 1,152 of the long period variables, and 546 of Nova Aquilae, No. 3. A discussion of the light curve of this new star is in process of publication. For it, 6,137 observations were received from 240 observers in 29 countries.

The discussion of the observations of long period variables for the years 1905 to 1917, inclusive, is well advanced. For this purpose, Mr. C. L. Brook, Secretary of the Variable Star Section of the British Astronomical Association, has furnished much valuable

material. In all, 16,941 visual observations have been made or received here, distributed as follows: —

F. C. Butterworth, 1,427; W. J. Luyten, 1,236; C. Y. McAteer, 1,208; J. F. Skjellerup, 1,125; L. Campbell, 1,016; T. C. H. Bouton, 838; J. M. Baldwin, 792; A. W. Long, 782; B. H. Dawson, 775; McCormick Observatory, 745; L. C. Peltier, 590; H. C. Bancroft, Jr., 587; Ed. de Perrot, 514; N. Tapia, 506; D. B. Pickering, 495; H. C. Wilson, 445; A. S. Young, 438; Ed. de Janczewski, 367; C. S. Mundt, 333; S. C. Hunter, 268; C. T. Whitehorn, 245; G. Houdard, 238; H. W. Vrooman, 209; I. L. Murray, 150; B. Berloty, 109; G. B. Lacchini, 105; H. Thomson, 103. Besides these, 1,390 observations were communicated by 46 observers, each of whom made less than 100 estimates.

About four hundred photographic charts of variable star regions have been furnished to observers, chiefly in the southern hemisphere. All descriptive data are now marked on enlarged negatives, so that paper prints made from them are ready for the observer without additional marking. This work has been done for the most part by Miss Mabel A. Gill, and will be the means of saving considerable labor in the future.

Mr. Howard Eaton, a graduate student of the University, has undertaken the photometric determination of new sequences for additional variable stars. His work is that of a volunteer observer.

The study of globular clusters has been extended by the aid of Miss Woods, who has found two open clusters to be rich in variables, N. G. C. 3201 and N. G. C. 6362. They contain fifty-six and fifteen variable stars, respectively. Very few globular clusters now remain in which stars brighter than the sixteenth magnitude have not been examined.

Miscellaneous

Phillips Library. — The Library has increased during the year by the addition of 609 volumes and pamphlets, making the total number at the present time 56,316.

Telegraphic Announcements. — Nineteen announcements of astronomical discoveries have been sent to Europe and South America. Code messages, which were not permitted during the war, are again in use. Cablegrams addressed to "Observatory, Boston," and telegrams to "Harvard College Observatory, Cambridge, Mass.," are given all desired distribution in this country and abroad.

Twenty-five Bulletins have been issued, making 694, in all. These Bulletins supplement the cablegrams and telegrams, but contain much additional information. Telegrams are sent at cost to subscribers, who receive the Bulletins without extra expense.

Publications. — The following Annals have been issued during the year: — **78**, Part **3**, Variable Stars in the Cluster Messier 15; **81**, No. **1**, Proper Motions of Stars in the Zone $-9° 50'$ to $-14° 10'$; **82**, No. **1**, The Harvard Station in Jamaica; **82**, No. **2**, Measurement of Close Double Stars with a Small Telescope; **83**, No. **3**, Observations and Investigations made at the Blue Hill Meteorological Observatory in the year 1918; **85**, No. **1**, Standards of Magnitude for the Astrographic Catalogue; **92**, The Henry Draper Catalogue, 4^h, 5^h, and 6^h; **93**, The Henry Draper Catalogue, 7^h and 8^h. Printing has been begun on several other volumes of the Annals, and, as indicated at the beginning of this report, about twelve volumes are nearly or quite ready for the printer. Nine circulars have been published during the year, as follows: —

211. Globular Clusters. October 31, 1918.
212. Maxima in 1919 of Variable Stars of Long Period. November 6, 1918.
213. Publications issued in 1918. January 1, 1919.
214. Astronomical Fellowships for Women. March 29, 1919.
215. Perturbation of Neptune. May 1, 1919.
216. Variable Stars in the Cluster N. G. C. 3201. May 24, 1919.
217. Variable Stars in the Cluster N. G. C. 6362. June 24, 1919.
218. 10 New Variable Stars in Harvard Maps 25 and 28. August 14, 1919.
219. 200317. Nova Sagittae. H. V. 3518. September 18, 1919.

S. I. BAILEY, *Acting Director.*

SEVENTY-FIFTH

ANNUAL REPORT

OF THE

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OF

HARVARD COLLEGE

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1921

THE OBSERVATORY

To the President of the University: —

Sir, — The work of the Astronomical Observatory during the past year has consisted chiefly in carrying onward toward completion the various researches begun under the supervision of the late Director, Edward C. Pickering. Special studies, however, have been undertaken, which are referred to below under the different departments.

In spite of financial difficulties, the publication of the Henry Draper Catalogue of stellar spectra has made good progress. We may hope, at the present rate, to complete the printing of this great work within three years. The demand for the remaining volumes is still urgent. A limited amount of publication has been done also in other lines, but the printing of the greater part of the material, which has been ready for a long time, has been delayed and is liable to indefinite postponement unless additional funds become available. It is evident that hereafter the greatest brevity consistent with accuracy will be necessary.

The year has yielded interesting results in the systematic search for new stars. Four such objects have been discovered, two by Miss Mackie and two by Miss Woods. Some of these have aroused the interest of astronomers at the other large American observatories. Also, a third maximum of the unusual star, T Pyxidis, was found during this search by Miss Woods. The preceding maxima occurred in 1890 and 1902. This star is related by the characteristics of its spectrum to novae having a single maximum. The four novae discovered in 1920 and the two in 1919 are all found in a small area of the Milky Way, between sixteen and twenty hours of right ascension. The remaining area, although examined with equal care during this time, yielded no new star. The brilliant new star in Cygnus, first seen by Denning of England, has been carefully followed and a fairly complete record of its changes in brightness and spectrum has been obtained. A bright nova is likely to be found more promptly visually than photographically, since the photographic method involves a certain delay. This star, however, was present on Harvard plates before its maximum and would have

been found in regular order within two or three days. So many observers in different parts of the world are now watching the sky that a brilliant new star can hardly escape notice more than a few hours, while objects fainter than the third or fourth magnitude might easily be overlooked. The photographic survey extends to about the ninth or tenth magnitude, and in many cases to much fainter stars. During this search, twenty new variables were discovered. This number is much less than might have been expected and indicates that the recent survey of the sky for the detection of variable stars was reasonably complete for the stars examined. Also, known novae were found 17 times, known variables 230, asteroids 16, and planets 25 times. These results furnish a check on the thoroughness of the search.

The astronomical fellowships for women have been filled by Miss Mary D. Applegate and Miss Antonia C. Maury. Miss Applegate has taken part in the measurement of novae and variable stars, and Miss Maury has been engaged in a study of the orbits of spectroscopic binaries discovered at this Observatory.

Dr. Joel H. Metcalf has undertaken an examination of some of the early and late plates of the northern sky for the detection of stars of large proper motion. Mr. Metcalf is carrying on this investigation by means of a "Blink" comparator constructed by himself. A systematic research of this nature should lead to results of much value.

Henry Draper Memorial

Much time has been spent by Miss Cannon in supervising the publication of the Henry Draper Catalogue. The first six volumes have now been issued or sent to the printer. The copy for the remaining volumes, **97**, **98**, and **99**, is entirely ready, and only lack of funds prevents their immediate publication. The demand for individual spectra from the unpublished volumes still continues, and, during the last few months, about 1500 have been sent to astronomers in this country and abroad.

A discussion of the spectrum of Nova Aquilae, No. 3, including a short comparative study of the spectra of all the novae, fifteen in number, which appear on the Harvard photographs, has been published; also, lists of spectra whose peculiarities led to the discovery of seventy-three new double stars and six new variable stars. A study of the spectrum of Nova Cygni, No. 3, has been commenced. Its light curve has been unusually regular, and the startling changes

which took place in the spectrum of Nova Aquilae, No. 3, have not yet occurred.

Considerable work has also been done by Miss Cannon on the subject of the distribution of the spectra of all the stars classified in the Henry Draper Catalogue. The spectra of some peculiar objects, including η Carinae, have been studied on all available plates.

The total number of plates exposed at Cambridge, under the direction of Professor King, was 4050, of which 3571 were photographs of the stars. The number of successful plates taken for the position of the Moon was 71. An adequate number of plates has been taken for the position of Uranus and Neptune. Plates have been taken, also, in the search for a transneptunian planet according to data furnished by Professor W. H. Pickering.

The work with the 8-inch Draper Telescope, using the out-of-focus method, for the photovisual magnitudes of stars and bright planets has been continued. Care has been taken to photograph the planets on ordinary plates also, whenever the photovisual values were found, in order to eliminate the effect of phase on the color indices.

In continuation of the work begun previously, some measures of the light of the sky have been made, using both blue and yellow light. These measures will determine the color index of the sky.

For determining and testing the elements for the orbits of spectroscopic binaries, charts of standard velocity-curves have been prepared by Professor King, which are applicable to any star, if its curve be drawn to the standard linear lengths for period and amplitude. Another set of curves shows the relation between eccentricity and periastron distance from the node.

In extension of the systematic methods used with the 1-inch Cooke lens for the prompt discovery of new stars, the list of regions for the Voigtländer lens, which photographs a circular area of the sky 60° or more in diameter, has been arranged to cover practically all the sky every clear evening. On alternate nights the centers of the plates come at the corners of the regions photographed the preceding night. In winter it is possible in a single night to cover all the sky except small portions low in the north and in the south. In summer the work requires perhaps two nights.

A slide rule for converting Cambridge Sidereal Time into Greenwich Mean Time (decimals of a day) has been made by Professor King, and its use has been found expeditious as well as accurate for the purpose.

The 7½-inch Cooke Triplet lens of the Maria Mitchell Nantucket Observatory has been tested with the result that the central component was adjusted to give much improved images.

Boyden Department

Arequipa Station. — The Arequipa Station has remained in charge of Mr. F. E. Hinkley, assisted by Señor J. E. Muñiz. In all, 3243 photographs of the sky were made. Two thousand two hundred and ninety-nine of these were taken with the 10-inch Metcalf Telescope for the determination of photographic magnitudes. The plates needed for this investigation can probably be completed within a year or two. The dome of the 13-inch Boyden Telescope, which had been in use about thirty years and had become unmanageable, has been equipped with a new rail and trucks. An effort has been made to maintain all the instruments and buildings in suitable repair.

Mandeville Station. — The Mandeville Station has continued under the direction of Professor W. H. Pickering. The planet Mars has been observed throughout the year, which precluded the usual series of measures of the shapes and rotation of Jupiter's satellites. The main features of this apparition have been the increasing numbers of the canals, which as anticipated reached their maximum at the time of the summer solstice of the planet. The diminished radius of curvature of the polar canals indicates a reduced velocity of the polar winds with the diminished size of the snow cap. The appearance of equatorial frosts and the sudden appearance, for a brief period, of extensive snow storms give a clue to the temperature conditions of the surface. An unusually prolonged duration of cloud over the south polar regions and temperate zone was observed. A report of these matters has been prepared, and will shortly be published. Drawings from the other members of the International Association have been received and will form another report.

Detailed observations of the lunar craters Conon and Eratosthenes have been continued, with especial relation to the appearance within and around them of snow and vegetation. A paper on each has already appeared, and another on the latter crater is now nearly ready for publication, in which by both drawings and micrometer measurements the daily changes in shape and dimensions of the dark patches due to vegetation are illustrated.

Considerable time has been given to locating the unknown planet whose orbit lies next beyond Neptune, and accordant results have

been already obtained. It is hoped to issue a statement shortly. Popular articles have been published on Relativity, the Time Relations of Astronomy and Geology, on Planetary Genesis, on Meteors, and Novae.

Photographic Magnitudes

This work has been continued under the supervision of Miss Leavitt. The taking of plates in series, with the 16-inch Metcalf Telescope, for the comparison of stars in selected regions with those of the North Polar Sequence is nearly completed, and the plan for covering the northern sky with similar plates is progressing. The number of series is 13 with blue, and 7 with yellow light. With the 10-inch Metcalf Telescope at Arequipa 71 series were taken with blue and 117 series with yellow light for the comparison of all parts of the southern sky with Harvard Standard Regions at the declination $+15°$. These plates have been of exceptionally fine quality during the past year. About 25,000 measures have been made of the brightness of stars in sequences, mainly in the southern heavens. The measurements of stars in twenty sequences within five degrees of the North Pole have been completed. An important feature of the work, as usual, has been the observation of variable stars and other objects of interest, especially novae. Many requests for information concerning suspected objects have been answered. The variables in the Nebula of Orion have been the subject of detailed study. Within the year the material for determining the magnitudes of comparison stars for the variables in the Magellanic Clouds has become available, and a beginning has been made in observing the brightness of these objects, more than 1700 in number. The number of estimates of brightness of variable stars was about 10,000.

Variable Stars

Mr. Campbell has observed variable stars with the 12-inch and 15-inch telescopes, when too faint to be seen with the smaller instruments used by amateur observers, or when they would otherwise be neglected. With the photometers attached to these instruments he has secured 7061 settings, of which 2536 were of the minor planets, for evidence of variation in light, 496 of Nova Cygni, No. 3, 524 of Algol and short period variables, and 413 of six eclipses of Jupiter's satellites. The remaining settings were of special variables, principally of long period, and of comparison stars.

Contributions have been received from the members of The American Association of Variable Star Observers, from observers in foreign countries, including Dr. J. M. Baldwin, of Victoria, Australia, and the Variable Star Section of the Cape Astronomical Association, South Africa, under the guidance of Mr. J. F. Skjellerup. The aid of the Director of the McCormick Observatory in supplying data when the variables are faint has been invaluable.

In all, 18,437 observations by 76 observers have been made or communicated as follows: —

J. F. Skjellerup, 1346; G. B. Lacchini, 1301; L. C. Peltier, 1226; C. Y. McAteer, 1169; J. M. Baldwin, 1137; L. Campbell, 1060; McCormick Observatory, 951; H. C. Bancroft, Jr., 699; A. W. Long, 696; T. C. H. Bouton, 571; D. B. Pickering, 517; E. de Perrot, 479; E. W. Janczewski, 441; A. S. Young, 407; C. S. Mundt, 384; N. V. Ginori, 376; R. G. Chandra, 368; E. W. Clement, 326; B. H. Dawson, 301; T. S. Kimball, 261; A. Bemporad, 249; H. O. Eaton, 239; J. E. G. Yalden, 226; W. T. Olcott, 222; N. Tapia, 214; P. W. Merrill, 209; S. L. Rhorer, 209; I. Yamamoto, 208; H. W. Vrooman, 182; S. C. Hunter, 154; S. Bunch, 143; C. C. Godfrey, 118; C. E. Barns, 115; E. E. Barnard, 111; L. M. Jenkins, 109; F. J. Carr, 106; M. J. Jordan, 100; R. O. Suter, 100. Besides these, 1407 observations were communicated by 39 observers, each of whom made less than 100 estimates.

The discussion of all these observations of long period variables has been carried on by Mr. Campbell, and numerous mean light curves have been carefully determined. These curves are remarkably complete and enable one to predict future dates of maxima and minima with considerable accuracy.

About 650 photographic charts of variable star regions have been furnished to observers, including a large number to the Chart Committee of The American Association of Variable Star Observers, which is making a complete revision of its charts on the Harvard scale of magnitude.

Mr. Howard Eaton, a graduate student of the University, has made photometric observations of a few variables and of new sequences of comparison stars.

Some progress has been made in the systematic study of the variable stars in the globular clusters.

Construction and Equipment

Professor Gerrish, as in other years, has had charge of the department of Mechanical Engineering, and has also acted as business executive of the Observatory. Rigid economy has been necessary. Sufficient repairs have been made to prevent undue deterioration of plant and equipment. Much of this work has been done by the regular Observatory employees, thus avoiding the employment of outside labor at the present high rates.

A new type of polarizing photometer is under construction in which the readings are to be automatically printed upon a strip of paper. By the use of this instrument it is expected that the services of a recorder will be dispensed with, the observer being enabled to record his own observations.

Miscellaneous

Phillips Library. — Nine hundred volumes and pamphlets have been added to the Library during the year, making the total number at the present date 57,216.

Telegraphic Announcements. — For many years the Harvard College Observatory has been the American center for the distribution of astronomical news, whether domestic or foreign. The great war caused some interruption in this service. At its close, the International Astronomical Union was formed, under the auspices of the International Research Council. A Committee on Astronomical Telegrams was appointed, and the Royal Observatory at Uccle (Brussels) was made the head of the service, with the Harvard College Observatory the distributing center for North and South America. During the year twenty-one telegraphic announcements were made. As heretofore, cablegrams from any part of the two Americas should be addressed to Observatory, Boston, and telegrams, to Harvard College Observatory, Cambridge, Mass.

Thirty-seven Bulletins have been issued, making 731, in all. These Bulletins supplement the telegraphic service, and make announcements of new stars, comets, variable stars, and other important astronomical news.

Publications. — The following Annals have been published during the year: — **81**, No. 2, The Light Curve of Nova Aquilae, No. 3; **81**, No. 3, The Spectrum of Nova Aquilae, No. 3; **81**, No. 4, Photovisual Magnitudes of Stars and Planets; **82**, No. 3, The Transneptunian Planet; **83**, No. 4, Observations and Investigations made at the Blue Hill Meteorological Observatory in the year 1919; **84**,

No. 4, Discussion of Thirteen Circumpolar Variables; and **94**, The Henry Draper Catalogue, 9^h, 10^h, and 11^h. **84**, No. 5, Photographic Light Curves of Eleven Novae, and **95**, The Henry Draper Catalogue, 12^h, 13^h, and 14^h, are in type, and **96**, The Henry Draper Catalogue, 15^h and 16^h, nearly so. Two circulars have also been issued, as follows: —

220. Maxima in 1920 of Variable Stars of Long Period. December 1, 1919.

221. Stars having Composite Spectra. Seventy-three New Double Stars.
Stars having Peculiar Spectra. Six New Variable Stars. January 28, 1920.

S. I. BAILEY, *Acting Director*.

SEVENTY-SIXTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1921

BY

S. I. BAILEY

CAMBRIDGE, MASS.
PUBLISHED BY THE UNIVERSITY
1922

THE OBSERVATORY

To the President of the University: —

Sir, — The staff of the Astronomical Observatory has suffered serious loss in recent years. Following the death of Professor Pickering, the late Director, in 1919, the Observatory lost two of its members in 1920, Miss Selina C. Bond and Professor Arthur Searle. Miss Bond was the daughter of the first director of the Observatory and an assistant under later directors. Professor Searle was a member of the Observatory for more than forty years and for many years Phillips Professor of Astronomy.

Dr. Harlow Shapley, formerly of the Mount Wilson Observatory, California, was called to this Observatory during the past year, as Observer. He has carried on studies of variable stars, and has made experiments on the measurement of the colors of stars. He finds that cluster type variables exist in the Small Magellanic Cloud. This result is of importance in estimating the distances of globular clusters and in determining the scale of the Galactic System, as it helps to establish the connection between the long period and the short period Cepheid variables, which have been used in his photometric methods of determining great distances.

Dr. Shapley and Miss Cannon are engaged in making a discussion of the distribution of the stars of different spectral types and magnitudes, which occur in the Henry Draper Catalogue.

A new line of work of large extent and of much significance in studies of the structure of the stellar system, and one specially suited to the equipment of the Observatory, is being opened up by the investigations of stellar distances. Several years ago, from a study of Harvard plates, Dr. Shapley found that very good estimates of the distances of stars could be obtained from spectra made with objective prisms. His present association with the Observatory has permitted the further study of this problem. The preliminary results are highly satisfactory. In this research, the value of an observing station in the southern hemisphere is demonstrated. Nearly all of the observatories where stellar distances are measured are located in the northern hemisphere, and the distances of southern stars, as a consequence, are little known. There has, accordingly, been a troublesome incompleteness in the study of the

distribution of stars in space. It now appears probable that the Harvard Observatory will be able to fill the need for the distances of southern stars, chiefly by the use of photographs already existing in the Harvard photographic collection.

The systematic photographic survey of the sky for the discovery of new objects of interest has been continued during the year, and two new stars have been discovered by Miss Woods on photographs of the Milky Way. In addition, a large number of new variable stars have been found. Lists of sixty-seven such objects have been published in Circulars 224 and 225, discovered by Misses Cannon, Applegate, Harwood, Mackie, Walker, and Woods.

The astronomical fellowships for women have been filled by Mrs. Mary Applegate Beach and by Miss A. Grace Cook. Mrs. Beach made photographic observations of variable stars. Miss Cook of Stowmarket, England, was engaged in the observation of meteors. This is the first time that the fellowship has been awarded to an English woman.

Dr. Joel H. Metcalf is still engaged in his study of large proper motion with the "Blink" comparator.

Good progress has been made in publication, especially of the Henry Draper Catalogue. Friends of the Observatory have contributed largely to this result. Through the generosity of Mr. and Mrs. C. W. Elmer, an offer of a thousand dollars was made by The American Association of Variable Star Observers to hasten the publication of the Catalogue, with the condition that an equal amount should be received from some other source. This condition was promptly met by Mrs. James R. Jewett, who, in addition, has generously offered to defray the expense of the final volume, H. A. **99**, the ninth volume of the Catalogue. This assures the prompt appearance of the remaining volumes.

Henry Draper Memorial

From an examination of the plates of the Henry Draper Memorial, twenty-seven stars having bright lines in their spectra have been discovered by Miss Cannon, sixteen of which are new variable stars. Two new double stars were found by means of their spectra, and six more of the uncommon stars of Class R.

A special study has also been made by Miss Cannon of the Large Magellanic Cloud. The number of objects having bright lines in their spectra in this region has been increased from forty-eight to sixty-one. The stars of Class O in this Cloud, thirty-three in all, comprise nearly one third of the total number now

known to exist in all parts of the sky. Some of them are of the fourteenth magnitude, or three magnitudes fainter than any so far known outside of this Cloud. Five additional stars of the P Cygni type were also found in this survey, the faintest of which is of magnitude 13.2. Numerous stars whose spectra are of Class B, some of which are as faint as the eleventh magnitude, exist in this Cloud.

The spectra of nine variable stars in the Large Cloud were found to belong to Classes from K5 to Mc. While the light curves of these stars have not yet been determined, at least five of them appear to be Cepheids.

A similar study of the Small Magellanic Cloud was made with the result that only one new gaseous nebula was found, making a total of three objects having spectra containing bright lines.

The supervision by Miss Cannon of the printing of the Henry Draper Catalogue has occupied considerable time.

The number of the photographs of the stars made at Cambridge by Professor King or under his direction during the year was 4,427. The total number of plates made was 5,091. The number of successful photographs taken for the position of the Moon was 39. This work was discontinued in April. Plates were also made of Uranus and Neptune, and for the detection of Planet O, according to data furnished by Professor W. H. Pickering.

The work with the 8-inch Draper Telescope, by means of out-of-focus images, for photo-visual magnitudes of bright stars and planets, has been continued. A preliminary reduction of these observations gives the photo-visual magnitudes for forty-four stars, and shows that the color value of this system is slightly toward the red end of the spectrum as compared with the photometric magnitudes of H. A. **50**. Many measures of the photographic magnitudes of the bright planets have also been made. Photographs of the brighter asteroids, when near opposition, have also been taken.

Plates received from Arequipa, which were taken for the photo-visual magnitudes of southern stars, have been measured and partly reduced.

The systematic tests of plates and standard lamps have been continued.

Boyden Department

Arequipa Station. — At the end of September, 1920, Mr. F. E. Hinkley, who had been in charge of the Station, was obliged for personal reasons to resign his position and return to the United

States. During the past year, therefore, the Station has been in charge of Señor J. E. Muñiz, who has been the only assistant. He has taken general care of the buildings and equipment, made regular meteorological observations, and carried on photographic work with a portion of the instruments. During the past year he secured altogether 1,214 photographs of the sky, 568 of which were made with the 10-inch Metcalf telescope for the determination of stellar magnitudes.

The stellar photographs obtained at Arequipa in the future as in the past will doubtless continue to play an important part in the plans of the Observatory, and it is hoped that the Station may be placed again on a more efficient basis during the coming year.

Mandeville Station. — The Mandeville Station remains under the direction of Professor W. H. Pickering, who has continued his observations of the Moon and planets. A careful, but unsuccessful, search was made for the suspected transneptunian Planet O, on plates made at Cambridge with the 16-inch Metcalf Telescope. The Station was temporarily closed in April and Professor Pickering left Jamaica for a year's rest and study in Europe, having been granted a sabbatical vacation by the Corporation.

Photographic Magnitudes

The taking and measurement of series plates for the purpose of obtaining the brightness of stars in all parts of the sky on the scale of the North Polar Sequence has been continued under the direction of Miss Leavitt. The number of such plates taken has been smaller than usual, but their quality has been exceptionally good. With the 16-inch Metcalf Telescope at Cambridge, nine series were taken with blue and sixteen series with yellow light, to be used for photographic and photovisual magnitudes, respectively. The number of plates in a series is usually twelve. The northern sky is now so far covered with this instrument that it is usually possible to obtain the approximate magnitude of any star north of declination $-15°$ without much delay. The process of covering the southern sky with the 10-inch Metcalf Telescope at Arequipa is somewhat more than two-thirds completed. The numbers of series taken for photographic and photovisual magnitudes were thirty-one and thirty-four, respectively. About 18,000 measures have been made on series plates, mainly for sequences of stars in the southern heavens. We now have magnitudes on file for about 35,000 stars.

As usual, many requests have been received for magnitudes of particular objects. The observation of variable stars and novae has also continued to be an important activity in this department. The number of such observations has been about 3,000.

Variable Stars

Visual observations of variable stars continue to be an important part of the working program. Mr. Campbell has continued in charge of this department, attending to the correspondence with Variable Star Observers and others outside the Observatory and preparing the monthly Bulletin which keeps observers informed of the stars which require most attention. He has also secured observations with the 12-inch and 15-inch telescopes, when especially needed. Nearly 1,200 estimates of the variables, chiefly during their faint phases, have been made, and 10,824 settings with the photometers attached to these telescopes.

Considerable time has been given to the observation of asteroids, for the detection of variability, and the determination of periods. The photometric settings were 5,662, on eight asteroids, of which Melpomene and Victoria appear to be certainly variable.

Five eclipses of Jupiter's satellites were observed. Special attention has been given to eclipsing variables and to some of the more interesting irregular variables.

The number of observations contributed to the Observatory by professional and amateur astronomers is the largest ever received, 24,018. Of these, 17,325 were communicated by The American Association of Variable Star Observers. Observations of southern variables by Dr. J. M. Baldwin, of Victoria, Australia, and by Mr. J. F. Skjellerup, of South Africa, are of great value. Professor Mitchell, Director of the McCormick Observatory, has continued to furnish observations of the variables when very faint. The detailed list of contributors is as follows:

J. M. Baldwin, 2913; L. C. Peltier, 1889; G. B. Lacchini, 1677; J. F. Skjellerup, 1527; N. V. Ginori, 1253; C. Y. McAteer, 1129; H. C. Bancroft, Jr., 796; R. G. Chandra, 759; The French Variable Star Association, 698; McCormick Observatory, 696; T. C. H. Bouton, 645; Ed. de Perrot, 612; G. Merton, 524; I. Yamamoto, 495; S. L. Rhorer, 467; W. H. F. Waterfield, 427; W. T. Olcott, 423; A. Bemporad, 415; D. B. Pickering, 382; C. S. Mundt, 375; A. S. Young, 350; Ed. Janczewski, 334; J. E. G. Yalden, 283; F. J. Carr, 254; A. W. Long, 225; J. Ellsworth, 215; E. W. Clement, 187; C. E. Barns, 174; C. C. Godfrey, 160; B. H.

Dawson, 150; P. S. Watson, 145; M. J. Jordan, 132; D. Potter, 125; S. K. Proctor, 122; A. E. Schwartz, 118; K. Reesinck, 118; G. C. Waldo, Jr., 115; M. E. Morris, 105; T. S. Kimball, 102; S. C. Hunter, 102. Besides these, 1784 observations were communicated by forty-eight observers, each of whom contributed less than 100.

The discussion of long period variables has been carried forward and considerable data for maxima and minima, as well as for light curves, are available. Predicted dates of maxima and minima continue to be made and appear to satisfy a real need.

Construction and Equipment

The plant and equipment have remained in charge of Professor Gerrish, who has continued to act as adviser in matters pertaining to engineering, and has also served as business executive.

An electrically driven vacuum apparatus has been installed in connection with the 16-inch Metcalf Telescope for springing photographic plates to a spherical curvature while in the telescope.

Indicating apparatus for the two-foot reflector has been designed and is under construction, by which the position of the telescope may be read from the observing deck above the instrument.

A simple instrument known as the Pole Finder has been devised, by which the position of the celestial Pole may be determined directly, and with moderate accuracy. The instrument is in two forms: one in which the eye is used unaided by optical devices; the other in which a small telescope serves to increase the accuracy of the determination.

A new visual method has been developed for adjusting the polar axis of an equatorial. A single adjustment, based upon two observations of Polaris, brings the axis accurately upon the Pole. Circumpolar stars are particularly advantageous for this purpose, affording a maximum degree of accuracy in both coördinates, but, owing to the difficulty of utilizing visual observations, their use hitherto has been confined almost entirely to photographic methods in which a large number of successive adjustments are required.

Miscellaneous

Phillips Library. — Nine hundred and forty volumes and pamphlets have been added to the Library during the year, making the total number at the present date 58,156.

Telegraphic Announcements. — This Observatory has continued to act as the American centre of the International Astronomical Union for the distribution of astronomical news, both domestic and foreign. During the year seventeen telegraphic announcements were made. Cablegrams from any part of North or South America should be addressed to Observatory, Boston, and telegrams, to Harvard College Observatory, Cambridge, Mass. Twenty-seven Bulletins have been issued, making 758 in all. These Bulletins in general supplement the telegraphic service. They serve for the announcement of new stars, comets, variable stars, and any other important astronomical news.

Publications. — The following Annals have been published during the year: — **81**, No. 5, Photographic Determinations of the Position of the Moon; **83**, No. 5, Observations and Investigations made at the Blue Hill Meteorological Observatory in the year 1920; and **95**, The Henry Draper Catalogue, 12^h, 13^h, and 14^h. **96**, 15^h and 16^h of The Henry Draper Catalogue, has been printed and is ready to send out, and **97**, 17^h and 18^h of the same Catalogue, is all in type. Five Circulars have been issued, as follows:

222. Predicted Maxima and Minima in 1921 of Variable Stars. December 15, 1920.
223. Observations of Saturn's Rings. January 3, 1921.
224. Stars Having Peculiar Spectra. 16 New Variable Stars. March 23, 1921.
225. Fifty-one New Variable Stars. May 2, 1921.
226. On the Relation of Spectral Type to Magnitude. July 30, 1921.

S. I. BAILEY, *Acting Director.*

SEVENTY-SEVENTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1922

BY

HARLOW SHAPLEY

CAMBRIDGE, MASSACHUSETTS
PUBLISHED BY THE UNIVERSITY
1923

THE OBSERVATORY

To the President of the University: —

Sir, — A sufficient summary of the progress of work at the Astronomical Observatory for the past year can be made by stating briefly some of the results obtained at Harvard on major problems of astronomical research. It will appear below that increasing emphasis is placed on the interpretation of the large amounts of data accumulated at present and in the past at the Harvard Observatory. Many of the researches described below are based entirely on the collection of photographs made in Cambridge and Peru during the last thirty-five years.

1. *Globular Clusters.* Studies of star clusters have led in recent years to far-reaching conclusions concerning the extent and structure of the stellar system. More than twenty-five years ago Professor Bailey began his investigations here of variable stars in globular clusters. Various types of work on these objects were later taken up at Mount Wilson and elsewhere, and now globular star clusters, and the variable stars of the Cepheid class which are numerous within them, are considered the most useful objects in the sky for the study of great distances. With the return of Professor Bailey to Arequipa in March of this year, active observation on globular clusters was again started, using mainly the 24-inch Bruce refractor — a very powerful instrument for the photography of faint stars. Many new variable stars have been found during the year in or near the southern globular clusters, and several series of photographs have been made in order to permit the investigation of the light curves of their Cepheid variables.

A new determination of the distances of all globular clusters is being based on angular diameters and integrated apparent magnitudes, as derived from photographs already existing in the Harvard collection. Several new globular clusters have been studied on Harvard photographs; among them is a faint and very distant system, N. G. C. 2419, in the constellation Lynx, which appears to increase appreciably the dimensions heretofore assigned to the stellar system. The greatest astronomical length yet measured is the distance of 350,000 light years separating the two globular clusters N. G. C. 2419 and N. G. C. 6715 — a value determined by the writer and published recently in Harvard Bulletin 776.

2. *Nebulae.* The Bruce photographic telescope at Arequipa has now to its credit the discovery of more than one-fourth of all the nebulae known. From photographic plates made with this telescope, about 3,000 nebulae were discovered some years ago by Professor Bailey, Dr. Stuart, and Mr. Frost. During the past summer more than 2,000 new nebulae have been found on Bruce photographs by Mr. Menzel, who spent some months as an assistant in the Observatory. The new nebulae are mostly in the southern sky, and with few exceptions appear to belong to the spiral family (which includes spindles and globular nebulae), although but a small number show the typical spiral arms. A projected study of the distribution of the spiral nebulae should assist materially in the determination of the relation of spirals to the galactic system.

Professor Bailey has given some attention to the photography of the large diffuse nebulosities of the southern Milky Way during the past summer. Estimates of the distance of the dark nebulosities in Taurus and Scorpio have been made by the writer as an incidental result in the study of the distribution of brighter stars. Mr. Menzel has found five new nebulae of the planetary type.

3. *Magellanic Clouds.* Two results of some significance have been derived during the past year from the studies at Harvard of the Magellanic Clouds. First, among the hundreds of variable stars in the Small Magellanic Cloud, the writer found several with periods of less than one day, thus affording a basis for the direct extension of the period-luminosity law of Cepheid variation; this result is of much importance in establishing the photometric method of measuring the distances of the globular clusters and the dimensions of the galactic system. Second, the distance of the Large Magellanic Cloud was found, from the measurement of five globular clusters discovered within its limits, to be somewhat in excess of one hundred thousand light years.

A continuation of the study of the Magellanic Clouds will yield absolute magnitudes of several kinds of peculiar giant stars. It is already evident that many stars in the Large Magellanic Cloud exceed the Sun in brightness by ten thousand times.

4. *Spectral Classification.* The eighth volume of the Henry Draper Catalogue of stellar spectra is now in press. The ninth and last volume will be printed during the coming year, the expense of publication being generously assumed by Mrs. James R. Jewett, who is a member of the Visiting Committee of the Observatory.

It has been decided to continue the spectral classification of faint stars, paying particular attention to the rich Milky Way

regions which are of most interest to various investigators of the structure of the sidereal universe. During the past summer Miss Cannon spent several months at Arequipa, where she made plates specially for the continuation of this work. She also photographed many objects of peculiar spectral class, and with the 13-inch Boyden telescope assisted in the observational work on the spectrophotometric parallaxes of bright southern stars.

5. *Long Period Variable Stars.* As in past years, the Harvard Observatory has been the center for the visual study of variable stars of long period. During the year about 25,000 estimates of magnitude have been received here and discussed by Mr. Campbell. The observers are largely amateurs, and are widely distributed on all continents. Between three and four hundred stars are followed systematically by seventy observers. The American Association of Variable Star Observers carries on an important part in this work.

A satisfactory explanation of the cause of variation has not yet been found for long-period variables, but the material now available at Harvard permits the derivation of significant statistical results concerning the distribution, spectral type, length of period, magnitude of variation, and form of light curve, and aids in the correlation of these properties with motion and absolute brightness.

To perpetuate its organization for work on long-period variables, the American Association of Variable Star Observers is now endeavoring to raise a fund as a memorial to the former Director of the Harvard Observatory, Professor E. C. Pickering, under whose guidance the Association was developed. It is proposed to operate this memorial fund in connection with the Harvard College Observatory.

6. *Cepheid Variable Stars.* Because of the fundamental part played by Cepheid variables in measuring great distances, much attention has been given to them at Harvard during the past year. Several have been discovered by Professor Bailey and Miss Woods. Miss Walker has determined the photographic light curve of Y Sagittarii, a bright Cepheid suspected of unusual variation. The periods of a few cluster-type Cepheids, both in the Magellanic Clouds and in or near globular clusters, have been determined. A study by the writer of the motion and absolute magnitude of the cluster-type Cepheid RZ Cephei shows that this faint variable has the highest known velocity yet found for any star — about 1,100 kilometers a second.

An analysis of available data on proper motions and radial

velocities for cluster-type Cepheids of the galactic system has brought out the remarkable fact that these stars appear to be moving with a high velocity to a southern part of the Milky Way. It is suggested that stars of this kind in the vicinity of the Sun have had a common origin in globular clusters or some other non-galactic system. The systematic motion of these variables is of the same order of magnitude as that found at Flagstaff for globular clusters.

7. *Binary Stars.* On account of their importance in studies of stellar evolution, systematic investigations of eclipsing binaries are maintained at Harvard, in some problems coöperating with the Princeton Observatory. Mr. Campbell and Miss Woods have made visual and photographic observations, respectively, and Mrs. Shapley has carried on the necessary orbital computations. Miss Maury has continued her investigations of spectroscopic binaries, using not only the great store of spectrum plates made in the past with Harvard telescopes, but also several new series of photographs made at Arequipa during the past summer with the Boyden telescope.

8. *Planetary Observations.* As in the past, Professor William H. Pickering, at the Mandeville Station of the Harvard Observatory, has observed the planets and the Moon. Special attention was paid to the atmospheric phenomena on Mars during the favorable opposition of 1922. Professor King has continued his photometric observations, determining both photovisual and photographic magnitudes of the planets. He has also developed an ingenious method for obtaining the brightness of different portions of the Moon's surface, and has made quantitative measures of "earthlight."

9. *Stellar Distances.* Knowledge of the structure of the local star system depends primarily on determination of the distances of the stars. Considerable progress has been made at Harvard in measuring stellar parallax from spectrum plates, particularly of the southern stars of Classes G, K, and M. Two circulars have been published on this subject. It appears that the parallaxes of several thousand stars can be determined from plates already existing in the Harvard collection.

10. *Stellar Statistics.* The study of the distribution of stars of different spectral classes and magnitudes, using the material contained in the Henry Draper Catalogue, has received special attention. Three problems have been studied: first, the structure of the nearer parts of the Milky Way; second, the relation of spectral

Classes B and A to the local cloud; and third, the relative frequencies of the various spectral classes down to magnitude 8.25.

By the death of Miss Leavitt on December 12, 1921, the Observatory lost an investigator of the highest value. She had obtained a comprehensive experience in photographic photometry, and had developed a clear appreciation of the difficulties involved in the theory and practice of this important research. Her work on standard magnitude sequences was nearly concluded at the time of her death, but she had hardly begun work on her extensive program of photographic measures of variable stars.

In the foregoing summary no mention has been made of Miss Leavitt's work on standard photometry, of the progress with the 60-inch reflector, of determinations of proper motion, of the discovery of two new stars by Miss Cannon and Miss Woods, or of the study of irregular variable stars by Mr. M. F. Jordan and others. Nor can space be taken more than to mention the change in the character of the Harvard Bulletins, which permits the rapid and economical publication of the Observatory's results; the rearrangement and cataloguing of the library; the Observatory's part in the first regular meeting of the International Astronomical Union at Rome, attended by the writer, where members of the Observatory staff were elected to eleven positions on the twenty-six international commissions. The public interest in the Open Nights for visitors, and in the popular lectures at the Observatory, emphasizes the need of a suitable assembly room or building on the Observatory grounds. The demand for tickets of admission continues to exceed the possibilities of accommodation.

The work of the Observatory is, to some extent, indicated in the bibliography of its publications during the year. In addition to articles published in Popular Astronomy, Proceedings of the National Academy of Sciences, Nature, and other scientific journals, more than eighty scientific papers or notes by members of the staff have been printed in the official publications of the Observatory. The following list contains the titles of the papers appearing as Harvard Circulars, and a partial list of those appearing in the Bulletins.

H. C. 227. Variable Stars. Predicted Maxima and Minima in 1922, by Leon Campbell.

H. C. 228. The Distances of Fifty Stars Determined from Objective Prism Spectra, by Harlow Shapley and Bertil Lindblad.

H. C. 229. The Local System and Stars of Class A, by Harlow Shapley and Annie J. Cannon.

H. C. 230. Spectral Class and Magnitude in Harvard Standard Regions, by Henrietta S. Leavitt.
H. C. 231. Stars having Peculiar Spectra. Eight New Variable Stars, by Annie J. Cannon.
H. C. 232. The Distances of 87 Bright Stars of Class K, by Harlow Shapley and Martha B. Shapley.
H. C. 233. The Orbit of the Spectroscopic Binary ζ Centauri, by Antonia C. Maury.
H. C. 234. Photographic Work at Arequipa with the Bruce 24-inch Refractor. N. G. C. 3201, by Solon I. Bailey.
H. C. 235. Observed Maxima and Minima of Variable Stars for 1921, by Leon Campbell.
H. C. 236. The Variations in Light and Color of Y Sagittarii, by Harlow Shapley and Arville D. Walker.
H. C. 237. Notes Bearing on the Distances of Clusters, by Harlow Shapley.
H. C. 238. Light Curve and Orbit of a New Eclipsing Binary, H. V. 3622, by Ida E. Woods and Martha B. Shapley.

H. B. 760. Nova Puppis (Miss Woods).
H. B. 761. A Fourth Variable of R Coronae Type (Campbell, Miss Cannon).
Dimensions of Messier 3 (Shapley).
H. B. 762. New Period for U Cephei (Campbell).
H. B. 763. Note on the Velocity of Light (Shapley).
Parallax of Messier 5 (Shapley).
H. B. 764. Giant Stars Near the Pleiades (Shapley).
New Variable in N. G. C. 6541 (Miss Woods).
Spectral Classification of Faint Pleiades (Miss Cannon, Shapley).
H. B. 765. The Absolute Magnitude of Cluster Type Variables (Shapley).
Two Irregular Variables of Class K (Jordan).
W Ursae Majoris (Campbell).
New Cluster Type Variable in Small Magellanic Cloud (Shapley).
H. B. 766. Eros and Palma (Miss Harwood).
H. B. 767. Note on Ionized Calcium in β Aurigae (Shapley, Miss Maury).
Variable Star of the W Cephei Type (Miss Leland).
H. B. 769. Note on Red Dwarf Stars (Shapley, Miss Wells).
H. B. 771. Abbreviation of Names of Constellations.
H. B. 772. Variable Dwarf Star (Miss Wells).
H. B. 773. Two Thousand New Nebulae (Menzel).
Nova Scorpii 1922 (Miss Cannon).
Star of High Velocity (Shapley).
H. B. 774. New Eclipsing Variable Star (Miss Woods).
Asteroids (Bailey).
Star with Variable Bright Lines (Shapley, Jordan).
H. B. 775. Group of New Globular Clusters (Menzel, Shapley).
Approximate Distance and Dimensions of Large Magellanic Cloud (Shapley).
Iris (Miss Harwood, Campbell).

HARLOW SHAPLEY, *Director.*

SEVENTY-EIGHTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1923

BY

HARLOW SHAPLEY

CAMBRIDGE, MASSACHUSETTS
PUBLISHED BY THE UNIVERSITY
1924

THE OBSERVATORY

To the President of the University: —

Sir, — A few of the researches now in progress at the Harvard College Observatory are selected for special comment in the present Annual Report. The partial bibliography on a later page will suffice to illustrate the nature of the investigations in hand. Particular attention has been given during the past year to the studies of stellar variation and the distribution of stars.

An important development is the initiation of an expedition from the Harvard station in Arequipa, Peru, to test an astronomical site near Calama, in northern Chile. It is hoped that the cloudy season prevailing in southern Peru from December to March may thus be avoided. The highly promising site on the Chilean desert may be tested for two or three seasons before we decide whether or not the southern station shall be permanently moved. Two telescopes will be taken from Arequipa by Dr. John Paraskévopoulos, formerly of the National Observatory at Athens, who takes charge of the southern station on December first. Professor Bailey, who has directed the work at Arequipa for the past two years, will return to Cambridge in December.

1. *Stellar Variation.* All classes of variable stars are under investigation at Harvard at the present time. More than fifty new variables have been announced by members of the staff during the past year. The importance of stellar variation in the evolution of the stars is now generally recognized, and all of our special studies are planned with the problems of stellar development and galactic structure in mind.

a. Novae. The photographic study of the light curves of novae, which was left unfinished by Miss Leavitt, has been continued during the year by Miss Walker and the writer. The photographic light curve of the famous new star of 1918 has been completed, with a thousand Harvard plates as the basis of discussion. For thirteen other novae the observations, made by the Pickering Fellows, and the light curves will be published soon in the Harvard Annals.

A star announced by Innes as a variable has been studied on Harvard plates, and is now assigned to the class of new stars, with the designation Nova Sagittarii 1917.5. It was independently dis-

covered as a nova by Miss Cannon while in Arequipa. Evidence is increasing that the novae and some types of irregular variable stars are closely associated, both in spectroscopic and photometric properties.

b. Irregular Variables. The discovery by Miss Cannon of one of the most remarkable irregular variable stars is reported in Harvard Bulletin 783. The star increased in brightness from 1890 to 1901, but for the last twenty years has been gradually fading. The spectrum is very peculiar, being basically of Class M but containing also some of the singularities of the spectrum of η Carinae. Extensive light curves of the well-known irregular variables SS Cygni and R Coronae have been published during the year. The principal work on irregular variation, however, is the continuation by Mr. Jordan of the study of variable stars of spectral class K. With few exceptions, all these appear to be of small range and non-periodic.

c. Long Period Variables. More than twenty-five thousand observations of long period variables have been received at the Harvard Observatory during the past year, two-thirds of which were made by members of the American Association of Variable Star Observers. The work of reduction is in the hands of Mr. Campbell, who has published various notes and summaries concerning the predictions of maxima and the analysis of observations. A discussion, nearly completed, of the periods of two hundred variables of this class, contains not only revised light elements, but the variations of the periods, and the forms of the light curves. The close affiliation of the Harvard Observatory with the Variable Star Association continues to be very fruitful in the study of this important class of stars.

d. Cepheid Variables. Professor Bailey, Miss Woods, and the writer have continued investigations of variable stars in the globular clusters and Magellanic Clouds. The Cepheid variables in the distant Milky Way clouds are also under investigation, in the hope that the spatial distribution can be determined. Many plates are being accumulated for this problem at both the northern and southern stations.

e. Eclipsing Binaries. Miss Maury has continued her investigations of the extremely difficult spectrum of β Lyrae. Photographic observations of eclipsing variables have been made by Mr. Rufus Suter and Miss Woods, and Mr. Campbell has made photometric observations of the high density binary, SW Lacertae. Special attention is being given to two types of eclipsing systems — those of very short period and high density, and the pairs with

large range of brightness. Both types are peculiarly significant in the problem of the evolution of close binaries. Mrs. Shapley continues to carry on the necessary orbital computations.

2. *The Nearby Stars.* An investigation of the various characteristics of the stars within ten parsecs of the Sun has been completed by Dr. Willem J. Luyten, who joined the staff of the Observatory in February. A thorough consideration of the stars in the solar neighborhood is of paramount importance in understanding the structure of the general system, for it is only near the Sun that the important stars of low luminosity can be found and measured. Dr. Luyten is led to interesting deductions concerning the frequencies of stellar masses, luminosities, velocities, and other properties. With respect to these nearby stars, the Sun moves with a velocity of twenty-five kilometers a second in the direction of right ascension 278° and declination +36°. (H.A. **85**, No. 5, in press.)

The continuation of the study of the nearby stars will be facilitated greatly by the examination of Harvard plates for large proper motions. Several hundred new photographs have been made recently in Arequipa and Cambridge of the star fields that were photographed with the same instruments thirty years ago. These plates will be examined in a special form of measuring machine which has been constructed in the instrument shop of the Yale University Observatory, under the direct supervision of Professor Schlesinger. The construction of this measuring engine was made possible through a gift from Mr. George R. Agassiz.

3. *Parallaxes.* Considerable progress has been made in the determination of stellar distances through the study of apparent magnitudes and spectral peculiarities. The published results for individual stars pertain so far only to those with spectra later than Class G0. Miss Adelaide Ames and Miss Helen Howarth have assisted the writer with the work on second type stars, and Dr. Priscilla Fairfield, of Smith College, is using Harvard material for a study of the absolute magnitudes for Classes B, A, and F.

Recent additions to our knowledge of the average absolute luminosity of many classes of stars has permitted the statistical determination by the writer of the distances of more than one hundred thousand of the stars of known spectral class and magnitude. (H. C. 243.) For a few classes, a usable average luminosity cannot be safely assumed; but for most of the stars in the Henry Draper Catalogue the distance can be estimated with an uncertainty of less than thirty per cent.

4. *Standard Photometry.* Professor King has completed for

publication in Harvard Annals **85**, No. 4, a revision of the magnitudes of the planets. His extra focal method has also been applied to the brighter stars, and the photographic magnitudes for a hundred of those in the northern sky are now in press.

The determination of photographic magnitude sequences in the Special Selected Areas has been completed and the results transmitted to Professor van Rhijn, who uses the material for the Harvard-Groningen Durchmusterung of faint stars in the Selected Areas. Harvard Annals **102**, giving the results for declinations $-15°$ and $-30°$, has been completed, and the next volume is nearly finished.

5. *Publications.* Some of the papers published in various scientific journals by members of the Observatory staff are now being issued in a series of reprints, copies of which are mailed with the Harvard Circulars. The titles of papers appearing in the Annals, Circulars, and Reprints during the past year are as follows: —

H. A. **81**, No. 7. Color Index and Photographic Light Curve of Nova Aquilae 1918.4 (No. 3). Harlow Shapley.

H. A. **85**, No. 2. On the Proper Motions of Stars in the Zone $-9°\ 50'$ to $-14°\ 10'$. Willem J. Luyten.

H. A. **86**, Part 2. Observations and Investigations made at the Blue Hill Meteorological Observatory in the year 1922. Alexander McAdie.

H. A. **98**. The Henry Draper Catalogue (19^h and 20^h). Annie J. Cannon and E. C. Pickering.

H. A. **102**. Durchmusterung of Selected Areas ($\delta = -15°$ and $\delta = -30°$). E. C. Pickering, J. C. Kapteyn, P. J. van Rhijn.

H. C. 239. The Distribution of Stars of Spectral Class B. Harlow Shapley and Annie J. Cannon.

H. C. 240. On the Spectral Constitution of the Nearer Parts of the Milky Way. Harlow Shapley.

H. C. 241. Variable Stars. Predicted Maxima and Minima in 1923. Leon Campbell.

H. C. 242. Comparison of a Milky Way Field with One at the South Galactic Pole. Solon I. Bailey.

H. C. 243. Distances of Two Hundred and Thirty-three Southern Stars. Harlow Shapley and Adelaide Ames.

H. C. 244. Observed Maxima and Minima of Variable Stars for 1922. Leon Campbell.

H. C. 245. The Distribution of Stars of Spectral Class M. Harlow Shapley and Annie J. Cannon.

H. C. 246. Distances of One Hundred and Sixteen Southern Stars. Harlow Shapley.

H. C. 247. Light Curves of the Two Abnormal Variables T and R Coronae Borealis. Leon Campbell and Harlow Shapley.

Reprint 1. Light and Color Variations of Nova Aquilae 1918.4. Harlow Shapley.

Reprint 2. On the Form of the Distribution Law of Stellar Velocities. Willem J. Luyten.

Reprint 3. On the Mean Absolute Magnitudes of the K and M Giants and the Systematic Errors in Trigonometric Parallaxes. Willem J. Luyten.

Listed below are the titles of some of the more important notes appearing in the Observatory's Bulletins, representing the work of Miss Ames, Bailey, Campbell, Miss Cannon, Miss Fairfield, Jordan, King, Miss Leavitt, Luyten, Menzel, Shapley, and Miss Woods:—

H. B. 776. New Globular Clusters. N. G. C. 2419.
H. B. 777. RZ Puppis. Five New Planetary Nebulae.
H. B. 778. Variables of Spectral Class S.
H. B. 779. Hydrogen Emission in Class B Spectrum.
H. B. 781. North Polar Sequence.
H. B. 783. Globular Cluster Containing Long Period Variables. Meteor Radiant.
H. B. 784. Eight Hundred and Fifty New Nebulae.
H. B. 787. Class K Stars of Peculiar Motion. Note on Distances of Class B Stars.
H. B. 788. Concerning Spectroscopic Tests of Stellar Luminosity. Report on a Photographic Survey for Bright Meteors.
H. B. 789. Star of Highest Density. Epsilon Indi.
H. B. 790. Fifteen New Variable Stars. First List of Suspected Objects.

HARLOW SHAPLEY, *Director*.

4/29/26

SEVENTY-NINTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1924

BY

HARLOW SHAPLEY

CAMBRIDGE, MASSACHUSETTS
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1925

THE OBSERVATORY

To the President of the University:

Sir, — The protection of the Harvard photographic collection against fire, the completion of the Henry Draper Catalogue, the expedition to northern Chile, the progress of researches on the chemistry of the stars, the initiation of an extensive investigation of the structure of the Milky Way, and the derivation of the distances of the Magellanic Clouds constitute six major factors in the past year's work at the Observatory.

1. *Fireproofing Building C.* Since the first photograph of a star was made at Harvard in 1850 under the supervision of Professor George C. Bond, the Observatory has been a repository for an ever-growing collection of astronomical photographs. The systematic photographic work with several telescopes was begun prior to 1900. Dozens of telescopes at the Observatory stations in Cambridge, Arequipa, and elsewhere have added to this collection. Some three hundred thousand plates are stored in Building C, nearly all of which are of value in current problems. The photographs made before 1900 are especially serviceable in the study of stellar motions and variability, and they are, of course, irreplaceable, and are unduplicated at other observatories.

The storehouse for these plates, Building C, is made of brick; but the floors, the plate cases, office desks, and other furniture are of wood. The great fire risk has long been a source of uneasiness to astronomers generally. Fortunately the danger has now been eliminated. Through the personal interest and generosity of members of the Visiting Committee, a special fund has been provided for the protection of the plates. A complete, automatic, sprinkler system has been installed throughout the building, and water curtains provided for the windows and doors on the side nearest the large wooden Observatory buildings. We can now feel sure that the Harvard photographic collection is secure from loss by fire. Tests have been made which show that damage by water need not be feared.

2. *The Henry Draper Catalogue.* Volume 99 of the Harvard Annals, which was completed and distributed during the past summer, is the last of the nine volumes of the Henry Draper Catalogue.

This extensive piece of work has been in progress for thirteen years, being planned in detail by Professor Pickering in 1911. The nine volumes contain for 225,300 stars the positions, the magnitudes, and the spectral classes as determined by Miss Cannon. The whole sky is covered by this survey, which is complete to magnitude 8.2 and also contains many thousands of stars as faint as magnitudes 9 and 10. The interpretation of the large amount of material has been considered in various papers published during the year. Much remains to be done, however, and at several other observatories analyses of the material in the Henry Draper Catalogue are in progress.

The completion of the catalogue by no means exhausts the possibilities of the Harvard Observatory in classifying the spectra of faint stars. It is conservatively estimated that on spectrum plates now existing in the Harvard collection there are a million faint stars still unclassified. During the past year a considerable number of long exposure plates have been made at Arequipa for the purpose of carrying on the work to fainter stars in selected regions. An extension of the catalogue is in progress, attention first being confined to regions of low galactic latitude, and to those parts of the northern sky for which the limit previously attained is not faint. Several thousands of these faint stars have now been classified by Miss Cannon, the laborious task of deriving photographic magnitudes is well advanced, and the first instalment of the Henry Draper Extension will be issued during the coming year.

3. *Expedition to Chuquicamata.* The expedition to northern Chile from the Harvard Station at Arequipa, mentioned in last year's report, was carried out successfully by Dr. Paraskévopoulos. The site chosen is near Chuquicamata, at an altitude of about nine thousand feet. During the season that is cloudy at Arequipa he succeeded in obtaining a large number of photographs with two different telescopes. To see whether the Chilean location would also be better than Arequipa throughout the whole year, Mr. L. B. Aldrich, of the Smithsonian Institution, at a station near Chuquicamata, is making nightly records of the observing conditions.

Meanwhile it is planned to test another site during the coming cloudy season, this time at San José in Peru, not far from Arequipa. If the conditions at San José show improvement over those at Arequipa, it is probable that for the time being, as a matter of economy, we shall retain the present site for the permanent estab-

lishment, transferring each year some of the instruments to San José for the cloudy season only. Arequipa is highly satisfactory for eight months of the year.

The observational work at Arequipa has progressed very satisfactorily in the hands of Dr. and Mrs. Paraskévopoulos. More than two thousand photographs have been made, the library has been extended and catalogued, some of the instruments have been overhauled and improvements made, and active photographic and visual work on variable stars has been begun.

4. *The Physical Chemistry of Stars.* Increasing knowledge of the structure of the atom and of its behavior under special conditions of pressure and temperature, have placed new emphasis on the detailed analysis of stellar spectra. During the year Miss Payne and Dr. Menzel have carried on important researches on the relative intensities of the absorption lines in different spectral classes. The observations are made almost wholly on spectrum plates already in existence in the Harvard collection. In particular, Miss Payne has been able to revise the temperature scale for the hotter stars, and to predict some of the higher ionization potentials for the lighter elements. The work on spectrum analysis has been expedited by the use of a new Moll thermoelectric microphotometer, which has been provided with the aid of grants from the American Academy of Arts and Sciences and the National Academy of Sciences. The study of stellar chemistry will be continued, with special emphasis on the stars of Class O and on the problems related to the temperature, density, and abundance of various chemical elements in stellar atmospheres.

5. *Variable Stars in the Milky Way.* The Cepheid variable stars, and to a lesser extent the eclipsing binaries and long-period variables, afford valuable means of measuring great distances. With the perfection of photometric methods, it becomes possible to analyze any part of the stellar system in which variables occur, outlining its extent in various dimensions, and the frequencies of certain types of stars. The problem of the structure of the galactic system has been of special interest to the writer for several years, and plans have now been perfected to place on a systematic basis one part of the analysis of the Milky Way.

Three belts in low galactic latitude are being photographed continually at Cambridge and Arequipa, with exposures of sufficient length to show stars to the seventeenth magnitude. Each one of the two hundred fields, which completely cover the galactic belt, will be photographed over a period of four or five years from five

to forty times annually. The accumulated material will be sufficient, in general, to determine the light curves and periods of all variable stars to the sixteenth magnitude, or fainter. More than a hundred new variable stars already have been found during the early stages of this work, and some important preliminary deductions are possible concerning the extent of the Milky Way.

The systematic study of the accumulating material cannot be made without the special provision of three or four assistants. Probably the most important need of the Observatory at this time is the provision of funds for carrying on this study of variable stars. The work can be accomplished expeditiously at the Harvard Observatory because of suitable telescopes, the collection of early photographs, and the long experience of the staff with photographic photometry and stellar variability.

6. *Magellanic Clouds.* Intermittent work on the Magellanic Clouds for the last twenty-five years has led finally to a determination of the distances and dimensions of these remarkable southern objects. Professor Issei Yamamoto has assisted during the past year in the study of variable stars in both clouds. His work on the periods of the variables and the continuation of the work on magnitude sequences have been the necessary steps in fixing the distances. Now that the distances are known, a wide field of investigation opens — namely, the derivation of the absolute luminosities of red variables, Class O stars, gaseous nebulae, globular clusters, stars of the P Cygni type, and other peculiar objects. It is of interest to reflect that we shall be able to find out more concerning the real brightness of such objects from a study of representatives that are one hundred thousand light years distant than we can learn from investigating those near at hand in the galactic system.

An investigation of the luminosity curve by the writer shows that in the Small Cloud there are a quarter of a million stars that are more than one hundred times as bright as the Sun, some of which have fifty thousand times the solar luminosity and are the brightest invariable stars on record. It is easily shown that these same stars are of enormous dimensions, some probably approaching in diameter the size of Jupiter's orbit.

Various Researches. The numerous other investigations in progress at the Observatory may be inferred from the partial bibliography given below. A few items are selected for brief summary in the following paragraphs.

A photometric survey by the writer, with the assistance of Miss Ames, of the brighter spiral nebulae and the condensations in the spiral arms, leads to the conclusion that Jeans' theory of the origin of the stars from spiral nebulae is untenable in its present form. Either the spiral nebulae are not at all stellar, or the distances assumed and computed by Jeans are much too small. The latter is almost certainly the case.

Thirty-five thousand observations of long-period variables have been received during the year and analyzed by Mr. Campbell. He has published the usual predictions and summaries, both of which have been widely used.

A report on the scientific value of lunar eclipses, with directions for observing them in such a way as to give information concerning the structure of the Earth's upper atmosphere, has been prepared and published by Mr. Willard J. Fisher, who has been a volunteer associate at the Observatory during the past year. Officers on eighty ships of the Navy of the United States coöperated in observing the lunar eclipse of August 14, 1924, and the results are now under discussion by Mr. Fisher.

Dr. Luyten, in collaboration at times with Professor E. B. Wilson, has completed numerous studies in stellar statistics. He has given special attention to the luminosity law and to the mean absolute magnitudes of special groups of stars.

The Bruce 24-inch telescope is being systematically used at Arequipa for long exposures on fields of faint nebulae, in continuation of a general study of nebular distribution. Nearly three thousand new nebulae have been described during the year, adding conspicuously to our information concerning these objects in the southern galactic hemisphere.

The relative frequency of different classes of stars in space is shown by a study of the Henry Draper Catalogue. Dwarf stars predominate. Class gM is more common than Class B. Class A stars decrease rapidly in luminosity with advancing spectral type.

A consideration of new variable stars in Sagittarius indicates that the bright star clouds in that region are not nearer than six kiloparsecs. A surprisingly large number of faint variables of long period are found in these distant star clouds.

In coöperation with the Kapteyn Astronomical Laboratory at Groningen, the Durchmusterung of Selected Areas has now been completed in volume **103** of the Harvard Annals. Standard magnitude sequences have also been determined for a number of

Kapteyn Special Regions, for the Magellanic Clouds, and elsewhere.

Continuing his work on stellar clusters, Professor Bailey has found and is studying a large number of new variables. Improved values for the distances of the clusters will be one product of his investigation.

The faint star cloud N. G. C. 6822, thought by Perrine, Duncan, and Hubble to be analogous to the Magellanic Clouds, has been studied on Harvard plates, and the distance estimated by various methods to be about a million light years. It is the most remote object now on record, and apparently lies well outside our Milky Way system.

Publications. The titles of papers appearing in the Annals, Circulars, and Reprints during the past year are as follows:

H.A. **82**, No. 4. Early Observations of the Elliptical Disks of Jupiter's Satellites. William H. Pickering.

H.A. **84**, No. 7. The Photographic Light Curves of Thirteen Novae. Arville D. Walker.

H.A. **85**, No. 3. Photovisual Magnitudes of One Hundred Bright Stars. Edward S. King.

H.A. **85**, No. 4. Revised Magnitudes and Color Indices of the Planets. Edward S. King.

H.A. **85**, No. 5. A Study of the Near-By Stars. Willem J. Luyten.

H.A. **85**, No. 6. Descriptions and Positions of 2,829 New Nebulae. Harlow Shapley, Donald H. Menzel, and Leon Campbell, Jr.

H.A. **86**, Part 3. Peruvian Meteorology. Solon I. Bailey.

H.A. **86**, Part 4. Observations and Investigations made at the Blue Hill Meteorological Observatory in the year 1923. Alexander McAdie.

H.A. **99**. The Henry Draper Catalogue (21^h, 22^h, and 23^h). Annie J. Cannon and Edward C. Pickering.

H.A. **103**. Durchmusterung of Selected Areas (between $\delta = -15°$ and $\delta = -90°$). E. C. Pickering, J. C. Kapteyn, P. J. van Rhijn.

H. C. 248. Spectral Class, Apparent Magnitude, and Galactic Position for Stars of the Henry Draper Catalogue. Harlow Shapley.

H. C. 249. Comparison of Photographic Measures made by Different Observers. Edward S. King.

H. C. 250. Long Period Variables. Predicted Maxima and Minima, 1924. Leon Campbell.

H. C. 251. List of Stars South of Declination $-20°$, Brighter than Apparent Magnitude 6.50, which are Presumably Nearer than Twenty-Five Parsecs. Willem J. Luyten.

H. C. 252. On the Absorption Lines of Silicon in Stellar Atmospheres. Cecilia H. Payne.

H. C. 253. Light Curve and Period of T Centauri. Leon Campbell.

H. C. 254. On the Dwarf Variable Stars in the Orion Nebula. Harlow Shapley.

H. C. 255. The Magellanic Clouds, I. The Distance and Linear Dimensions of the Small Cloud. Harlow Shapley.
H. C. 256. On Ionization in the Atmospheres of the Hotter Stars. Cecilia H. Payne.
H. C. 257. Notes on Jeans' Theory of the Origin of Stars. Harlow Shapley.
H. C. 258. A Study of Line Intensities in Stellar Spectra. Donald H. Menzel.
H. C. 259. Observed Maxima and Minima of Variable Stars for 1923. Leon Campbell.
H. C. 260. The Magellanic Clouds, II. The Luminosity Curve for Giant Stars. Harlow Shapley.

Reprint 4. Photovisual Magnitudes of One Hundred Bright Stars. Revised Magnitudes and Color Indices of the Planets. Edward S. King.
Reprint 5. On the Relative Velocity of Blue and Yellow Light. Harlow Shapley.
Reprint 6. Summary of a Study of Stellar Distribution. Harlow Shapley and Annie J. Cannon.
Reprint 7. The Brightness of Lunar Eclipses, 1860–1922. Willard J. Fisher.
Reprint 8. The Distribution of the Stars. Harlow Shapley.
Reprint 9. A Statistical Discussion of Sets of Precise Astronomical Measurements: Parallaxes. Edwin B. Wilson and Willem J. Luyten.
Reprint 10. A Statistical Discussion of Sets of Precise Astronomical Measurements, II: Proper Motions. Edwin B. Wilson and Willem J. Luyten.
Reprint 11. Notes on Some Statistical Consequences of the Luminosity Law. Willem J. Luyten.
Reprint 12. A Synopsis of the Ionization Potentials of the Elements. Cecilia H. Payne.
Reprint 13. Notes on Observing and Reporting Lunar Eclipses. Willard J. Fisher.

Listed below are the titles of some of the more important notes appearing in the Observatory's Bulletins, representing the work of Miss Ames, Miss Applegate, Bailey, Campbell, Miss Cannon, Miss Harwood, Miss Howarth, King, Miss Leavitt, Luyten, Shapley, Mrs. Shapley, Miss Woods, Yamamoto.

H. B. 791. Nine New Variables in High Galactic Latitude. Ceres. Elements and Light Curve of SX Hydrae.
H. B. 792. Note on Density of Stars in Space.
H. B. 793. Note on Hypothetical Solar Stream of Stars.
H. B. 794. Three Red Dwarf Stars. Second Report on Survey for Bright Meteors.
H. B. 796. Note on the Distance of N. G. C. 6822. Angular Dimensions of Magellanic Clouds. Contrasted Galactic Concentration of A and F Stars. Maxima of SS Cygni in 1923. Period and Light Curve of 2.1923 Librae.
H. B. 797. Absolute Magnitudes of Class A Stars. Orbit of SX Hydrae. Photographic Magnitudes in Messier 13. Z Andromedae, 232848.

H. B. 798. Enhanced and Low Temperature Lines in Spectrum of α Circini. Light Curve and Period of S Carinae. Spectrum of S Carinae. Occultation of Aldebaran.

H. B. 799. On Systematic Corrections to Greenwich Parallaxes.

H. B. 801. Peculiar Spectra in the Large Magellanic Cloud. On Systematic Corrections to Star Catalogues. Ten New Variable Stars near Globular Clusters.

H. B. 802. Dwarf Star of Small Proper Motion.

H. B. 803. Balanowsky's Nova in Messier 87. Proof of Variability of Fourteen Stars in Orion Nebula. Transit of Mercury.

H. B. 804. Note on a Star Cloud in Sagittarius.

H. B. 805. Completion of the Henry Draper Catalogue. Preliminary Report on the Brightness of Absorption Lines. Broad Absorption Band in Class A Spectra.

H. B. 806. Note on R, S, and T Coronae Australis.

HARLOW SHAPLEY, *Director*.

EIGHTIETH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1925

BY

HARLOW SHAPLEY

CAMBRIDGE, MASSACHUSETTS
PUBLISHED BY THE UNIVERSITY
1926

THE OBSERVATORY

To the President of the University: —

Sir, — The work of the Harvard Observatory during the past year can be conveniently summarized under the headings spectroscopic, photometric, and miscellaneous. The progress has been very satisfactory, thanks to the zeal and coöperation of the members of the staff. Better returns in research cannot reasonably be expected until the Observatory's equipment and personnel are strengthened, and this cannot be done as long as the endowment remains essentially as it was thirty-five years ago.

1. *Spectroscopic.* The most noteworthy item of the year in the spectroscopic work of the Observatory was the completion and publication of Miss Payne's monograph on Stellar Atmospheres. The publication of her work in the form of an octavo book of about 225 pages is a new departure for the Observatory. Heretofore the results of our researches have been published in the Annals, Circulars, and Bulletins, and in Reprints from the scientific journals. The monograph on Stellar Atmospheres initiates a series designed to contain intensive studies on special subjects. A gift from Mrs. James R. Jewett permits the Observatory to sell this first monograph at less than cost.

The book on stellar atmospheres covers a wide field, and appears at a time when the application of modern spectroscopic theory to astrophysical problems makes such a work of special importance. The present state of the general problem is set forth in the monograph, but its most important features are the contributions made by Miss Payne from her studies of Harvard spectrograms. Special attention may be called to the investigation of the relative frequency of the chemical elements in stellar atmospheres and the comparison of these data on relative abundance with the known facts concerning the chemistry of the Earth's crust. Other sections deal with the revision of the stellar temperature scale, the determinations of the critical potentials for various elements as determined from their behavior in stellar atmospheres, and the discussion of some stars of peculiar classes.

In last year's report the conclusion of the Henry Draper Catalogue was mentioned, and also the plans for an extension to fainter stars. Miss Cannon has continued her work on the Milky Way

fields, not only classifying the faint stars, but supervising the determination of the photographic magnitudes. The first number of Harvard Annals 100 has been issued, containing, as the initial instalment of the Henry Draper Extension, the positions, magnitudes, and spectra of four thousand stars mostly fainter than the ninth magnitude. The spectra of approximately seventeen thousand other stars in various Milky Way fields of the northern sky have already been classified for the Extension.

The Balmer series of hydrogen absorption lines in the region of short wave lengths in stellar spectra has been the subject of a special study by Miss Howe and Miss Payne. Large numbers of photographs already in the Harvard collection were found suitable for this research, and the 24-inch reflecting telescope, with its highly transparent prism, has permitted the extension of the photography of the violet end of stellar spectra beyond the limits usually set by the photographic refractors.

During the last year spectrograms have been made chiefly at the Boyden Station in Peru, where photographs for the Henry Draper Extension were made with the 10-inch Metcalf triplet, and where, with the 13-inch Boyden telescope, the systematic work on spectroscopic parallaxes has continued and spectrograms of southern binary stars have been obtained for Miss Maury's investigations.

The only completed study during the year on spectroscopic parallax is the analysis of the width of hydrogen lines in Class A spectra in relation to the problem of absolute magnitudes (H. C. 264). The work was carried through chiefly by Dr. Priscilla Fairfield, of Smith College, working at the Harvard Observatory.

2. *Photometric.* Several interesting photometric studies have been completed during the year, including Professor King's discussion of the solar corona of the total eclipse of January 24, 1925, and investigations of the Magellanic Clouds, in which I have had the collaboration of Miss Wilson and Professor Yamamoto. Professor Bailey, who retired from active service on February 1, has continued the discovery and study of variable stars in globular clusters. Miss Harwood has published a valuable summary of the variations in the light of asteroids. Her paper (H. C. 269) was of particular service for two of the committees of the International Union at its recent meeting. Mr. Campbell has published the usual summaries and predictions for long-period variables and has completed for publication an extensive report on results obtained between 1906 and 1920 by the observers of these stars.

The total solar eclipse of January, 1925, was studied by the Harvard Observatory with modest equipment. Special coronal photometers were operated at four stations — Buffalo, Poughkeepsie, New London, and Nantucket. At all but the first, the sky was clear at the time of totality and the observing program was carried through successfully. Professor King has discussed the results in a paper now in press. He finds the integrated magnitude of the corona to be -11.57 photovisually and -10.76 photographically, giving a color index of $+0.81$, which is comparable to that of the Sun. He has also determined the brightness of the corona in ultraviolet light, using a quartz lens and silver screen. He finds that for light of the wave length transmitted by this special apparatus the corona radiates, per unit area, approximately one fifth as much as is reflected by the Moon.

It was mentioned in last year's report that a knowledge of the distances of the Magellanic Clouds would open a wide field of investigation concerning stars and nebulae of high luminosity. Eight papers have been published during the year concerning the Magellanic Clouds. They deal with the following subjects.

(*a*) Determination of the linear dimensions of the Large Cloud. The diameter is 15,000 light years, or about twenty times the distance of the Sun from the Orion Nebula.

(*b*) Measurement of the absolute luminosities of large numbers of nebulae, clusters, and peculiar stars in the Large Cloud. The peculiar types include Cepheid variables, Class O stars, and objects of the P Cygni type.

(*c*) The super-giant variable star S Doradus, which is six hundred thousand times as bright as the Sun. Its diameter is probably nearly as large as that of the Earth's orbit.

(*d*) Dimensions of 30 Doradus and N. G. C. 604 — the two largest gaseous nebulae known.

(*e*) Comparison of the Large Magellanic Cloud with the spiral Messier 33 in size and brightness as an indication that the Magellanic Clouds belong to the same class of extraneous stellar systems as spiral nebulae.

(*f*) Absolute magnitudes and linear diameters of 108 diffuse nebulae in the Small Magellanic Cloud.

(*g*) Positions and descriptions of 170 nebulae in the Small Cloud that have hitherto not been catalogued.

(*h*) New determination of the photographic period-luminosity curve, based on an extensive study of the Cepheid variable stars in the Small Magellanic Cloud.

As in past years, much has been done on the photography of variable stars. In addition to Professor Bailey's work mentioned above, there have been studies of special variable stars by Mr. Campbell, Professor Yamamoto of Kyoto, Dr. Lassovszky of the Hungarian National Observatory, and others. Miss Cannon and Miss Woods have added a large number of new variable stars to the number already known in the Milky Way clouds, which are now under systematic investigation at Harvard.

Among other photometric studies are the determination of the integrated magnitude of a globular cluster by Mrs. Paraskévopoulos; studies of variability in the spectrum lines of β Lyrae and υ Sagittarii by Miss Maury; the continuation of Miss Leavitt's work on standard magnitudes by Miss Walker; and Professor King's photographic measures of earthlight. The photographic magnitude of earthlight is found to be -1.60 ± 0.20 (av. dev.). As seen from the Moon, therefore, the photographic magnitude of the "full" Earth is -16.3, which corresponds to one hundred times the brightness of the full Moon as seen from the Earth. As seen from the Sun, the photographic brightness of the Earth is -3.30, or about five times that of Sirius.

3. *Miscellaneous.* After the retirement of Professor W. H. Pickering, the 11-inch Draper telescope was returned from the station at Mandeville, Jamaica, and is now installed at Cambridge, for use in extra-focal photometry and the study of stellar spectra.

During the past year an astronomical site at San José, Peru, not far from Arequipa, was tested by Dr. Paraskévopoulos and assistants. Conditions during the cloudy season were not found to differ essentially from those at Arequipa. A generous gift from Mr. George R. Agassiz will permit the Observatory to send two telescopes in November of this year to Chuquicamata in northern Chile, where very successful results were obtained two years ago. With five telescopes, about 2500 photographs were made at Arequipa during the past year. Weather conditions were less favorable than usual.

A grant from the J. Lawrence Smith Fund of the National Academy of Sciences has made it possible for the Observatory to initiate a comprehensive investigation of the meteor trails on Harvard plates. The work is in the efficient hands of Dr. W. J. Fisher, whose long interest in the various phenomena of the Earth's atmosphere especially suits him for the investigation. During the year he has accumulated data on more than two hundred and fifty

meteor trails — the largest collection of material of this kind ever assembled. The results promise to be of much interest in an important but as yet little-worked department of astronomy.

The Bond Astronomical Club, named in honor of the first two directors of the Harvard Observatory, has been organized during the last year. The club includes both the professional and the amateur astronomers of the community. Its general educational program for the public and schools is well under way. Members of the club assist with the annual series of public Open Nights, which continue to be attended beyond the limits of space at the Observatory.

Dr. Georges Lemaître, of the University of Louvain, has studied the problem of the pulsation theory of Cepheid variables while at the Harvard Observatory as a Fellow of the C. R. B. Educational Foundation. His work will be published in a forthcoming Circular.

Mr. Paul Davidovich, formerly of Tashkent and Moscow, came to the Harvard Observatory in March as a Fellow of the International Education Board. He is investigating the Harvard spectra of novae, and with the 24-inch reflector is carrying on a program of photographic photometry of long-period variable stars.

Five members of the staff of the Harvard Observatory attended the meetings of the International Astronomical Union in Cambridge, England, in July. Members of the Observatory are on eleven of the international committees of the Union, and take an active part in the plans, conferences, and reports.

During the past summer Dr. and Mrs. Paraskévopoulos at Arequipa have carried on photometric and spectroscopic observations of Nova Pictoris, the remarkable second-magnitude new star that was discovered in May. The Harvard photographic plates show that from 1889 until as late as February 1925 the star had been of constant brightness at magnitude 12.7, photographically.

A number of interesting statistical investigations have been made by Dr. Luyten, many of them in collaboration with Professor E. B. Wilson. The nature of his work is indicated by the titles in the bibliography. Dr. Luyten has examined the possibility of a stellar companion to the Sun, but no star, with the possible exception of 46 Tauri, has the requisite space velocity. He has also measured the proper motions of some faint objects, including the nearest of stars, Proxima Centauri, and the planetary nebula N. G. C. 6572.

An important research bearing on the problem of giant and dwarf stars of Class M has been undertaken by Dr. Fairfield, using Harvard photographs of recent date and those made thirty or

forty years ago. The proper motions of nearly one hundred of the Class M stars between the visual magnitudes eight and nine and between declinations 50° and 60° south have already been measured. It is hoped to discriminate with these measures between giants, dwarfs, and intermediates, and thus decide how definite is the gap between giants and dwarfs.

4. *Publications.* The titles of papers appearing in the Annals, Circulars, and Reprints during the past year are as follows:

H. A. **85**, No. 7. Standards of Magnitude for the Astrographic Catalogue. Henrietta S. Leavitt.

H. A. **100**, No. 1. The Henry Draper Extension. Annie J. Cannon.

H. C. 261. The Variable Star RZ Cephei. Henrietta S. Leavitt.

H. C. 262. Remarks Concerning Recent Work on the Luminosity Curve, Willem J. Luyten.

H. C. 263. On the Spectra of Class O Stars. Cecilia H. Payne.

H. C. 264. The Relation of Hydrogen Line-Widths to Absolute Magnitude for Class A Stars. Priscilla Fairfield.

H. C. 265. Fifty-nine New Variable Stars. Annie J. Cannon.

H. C. 266. Variable Stars in the Cluster N. G. C. 6723. Solon I. Bailey.

H. C. 267. Photographic Measures of Earthlight. Edward S. King.

H. C. 268. The Magellanic Clouds, III. The Distance and Linear Dimensions of the Large Cloud. Harlow Shapley.

H. C. 269. Variations in the Light of Asteroids. Margaret Harwood.

H. C. 270. The Long Period Variable W Hydrae. Issei Yamamoto and Leon Campbell.

H. C. 271. The Magellanic Clouds, IV. The Absolute Magnitudes of Nebulae. Clusters, and Peculiar Stars in the Large Cloud. Harlow Shapley and Harvia H. Wilson.

H. C. 272. Long Period Variables. Predicted Maxima and Minima, 1925. Leon Campbell.

H. C. 273. A Statistical Study of the Brighter Class M Stars. Willem J. Luyten.

H. C. 274. Notes on Stellar Velocities. Willem J. Luyten.

H. C. 275. The Magellanic Clouds, V. The Absolute Magnitudes and Linear Diameters of 108 Diffuse Nebulae. Harlow Shapley and Harvia H. Wilson.

H. C. 276. The Magellanic Clouds, VI. Positions and Descriptions of 170 Nebulae in the Small Cloud. Harlow Shapley and Harvia H. Wilson.

H. C. 277. Period and Light Curve of SV Tauri. Charles Lassovszky.

H. C. 279. Observed Maxima and Minima of Variable Stars for 1924. Leon Campbell.

H. C. 280. The Magellanic Clouds, VII. The Photographic Period-Luminosity Curve. Harlow Shapley, Issei Yamamoto, and Harvia H. Wilson.

H. C. 281. Note on Obscuring Cosmic Clouds in High Galactic Latitudes. Harlow Shapley.

Reprint 14. A Statistical Discussion of Sets of Precise Astronomical Measurements, III; Masses of the Stars. Edwin B. Wilson and Willem J. Luyten.

Reprint 15. A Statistical Discussion of Sets of Precise Astronomical Measurements, IV; the Mass-Ratio in Binaries. Edwin B. Wilson and Willem J. Luyten.

Reprint 16. Notes on Stellar Statistics, II; the Mathematical Expression of the Law of Tangential Velocities. Willem J. Luyten.

Reprint 17. Notes on Stellar Statistics, III; on the Calculation of a Mean Absolute Magnitude from Apparent Magnitudes, Angular Proper Motions and Linear Radial Velocities. Willem J. Luyten.

Reprint 18. The Frequency Distribution on Apparent Magnitude of the Non-Magellanic O-Type Stars. E. B. Wilson and W. J. Luyten.

Reprint 19. Notes on Stellar Statistics, IV. On the Relation between the Mean Values of the v and τ Components of Proper Motion. Willem J. Luyten.

Reprint 20. Astrophysical Data Bearing on the Relative Abundance of the Elements. Cecilia H. Payne.

Reprint 21. A Tentative Classification of Long Period Variables. Leon Campbell.

During the past year seventeen Harvard Bulletins have appeared, containing seventy-four articles and notes. A few of the titles are listed below, representing the work of Bailey, Campbell, Miss Cannon, Luyten, Miss Maury, Paraskévopoulos, Mrs. Paraskévopoulos, Shapley, Miss Wilson, Miss Woods, Yamamoto.

H. B. 808. Statistics of Faint Nebulae. Period of RZ Pegasi.

H. B. 809. Note on RX Puppis. Twenty-Five New Variable Stars.

H. B. 813. Five New Variable Stars. Eight New Variable Stars near N. G. C. 6809.

H. B. 814. S Doradus, a Super-giant Variable Star. Note on a Possible Solar Companion.

H. B. 816. Two Giant Gaseous Nebulae. Comparison of Messier 33 and the Large Magellanic Cloud.

H. B. 818. Proper Motion of Proxima Centauri.

H. B. 820. Note on β Lupi.

H. B. 821. Nova Pictoris. Seven New Variable Stars.

H. B. 823. Harvard Observatory Monograph on Stellar Atmospheres. Photographic History of Nova Pictoris.

H. B. 824. Brooks' Comet. Integrated Magnitude of 47 Tucanae. The Secondary Spectrum and Mass Function of v Sagittarii. Note on the Proper Motion of the Planetary Nebula N. G. C. 6572.

HARLOW SHAPLEY, *Director.*

EIGHTY-FIRST

ANNUAL REPORT

OF THE

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THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1926

BY

HARLOW SHAPLEY

CAMBRIDGE, MASSACHUSETTS
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1927

THE OBSERVATORY

To the President of the University:

Sir, — Attempts to discover more of the detailed structure of the galactic system have attracted much attention in recent years, especially since the introduction of modern methods of measuring stellar distances has shown the vast extent of the star clouds in the Milky Way. Some progress in the study of galactic structure has been made at the Harvard Observatory during the past year through the initiation of systematic work on faint variable stars in low galactic latitudes. For forty years the photographic material has been accumulating for this general study of the variability of faint stars; and during the last five years a more concentrated observational attack has been in progress both at the southern and the northern stations. The plates have been made and the investigation has been planned as regular items on the program of the Observatory. But the study of the plates, which includes much work on magnitude standards, discovery and measurement of variable stars, and analysis of results, has required more workers than could be provided from Observatory funds. Fortunately it has been possible to obtain a grant from the Milton Fund of Harvard University for the special purpose of studying faint variable stars. The whole time of three workers and the part time of three or four others is now devoted to the problem. Some immediate results have been obtained; more than one hundred new variable stars have been discovered, and within two or three years significant contributions to the problem of galactic structure should be expected.

Researches on sidereal distances. The study of variable stars in the Milky Way clouds is but one of five lines of attack on the problem of sidereal distances. Two of the Observatory's researches, — proper motions and spectroscopic parallaxes — deal with nearer objects; and two concern the objects more remote than the average variable stars of the Milky Way, that is, the studies of the distances of globular clusters and of the extra-galactic nebulae. Results from all five sources should help to provide in a few years' time a fairly satisfactory picture of the general arrangement of known sidereal bodies. Of equal interest, however, these various studies should yield data on the nature of stellar variability, on the

frequency of luminosities for typical stars, on the higher organizations of clusters and nebulae, and on certain phases of stellar evolution.

The study of the distances and properties of the stars in the immediate vicinity of the Sun is a matter to which Dr. Luyten is giving special attention in his investigation of large proper motions. Through the comparison of early and recent plates, even on the small scale of many of the Harvard photographs, he is able to find and measure the apparent motions of considerable numbers of stars. The motions are discernible either because of the high velocities of the stars or because of their nearness. A complete survey of stars of large proper motion will thus aid materially toward the solution of two problems in astronomy: first, the number of stars of various intrinsic luminosities per unit volume of space; second, the distribution of cosmical velocities. It is important that the proper motion survey shall be complete to a definite limit of brightness and motion. At the present time we are not certain that we have complete information except for stars brighter than the sixth magnitude and for proper motions greater than 0″.2. It is hoped that an examination of the Harvard plates may eventually extend these limits to the eleventh magnitude and a quarter of a second of arc; but up to the present time it has not been possible to complete the series of recent plates.

The blink microscope, designed for the comparison of celestial photographs, was built for us by the Yale Observatory, and was put in operation in June, 1926. Attention has first been paid to the southern hemisphere, and especially to the series of plates taken with the 8-inch Bache refractor. At present there are available 350 plates, taken in 1922–23 (after which interval the instrument was temporarily dismantled), that duplicate regions covered by plates made with the same instrument in 1889–97. About 220 pairs of these plates have been examined, covering slightly less than half the sky between declination −30° and the South Pole. More than 1200 proper motions have been found, but up to the present time only 300 of these have been measured. No new proper motions have been found which exceed 1″.5, annually. The remaining 130 pairs of plates will probably be examined before the end of the calendar year, and it is hoped that the measures and reductions can be completed within a year.

Apart from the systematic program, the blink microscope has been used occasionally for examining miscellaneous plates. Among these may be mentioned one pair of plates with an interval of

twenty-six years, taken with the Bruce 24-inch refractor, with one hour exposure, and showing stars of the sixteenth magnitude. On an area of 16.5 square degrees eighty proper motions were found. None of these has yet been measured, but it is estimated that the majority exceed 0″.1, annually.

The region immediately beyond that part of the Sun's neighborhood which is involved in the proper motion survey is being explored by means of the spectroscopic method of determining stellar distances. During the year no distances have been determined at Harvard by this method, but the spectral analysis at the basis of the method is under investigation, and the accumulation of plates, with the 13-inch Boyden telescope at Arequipa, has been continued as in past years.

A general redetermination of the distances of globular clusters has been undertaken and will probably be completed during the next year. For this work the apparent magnitudes of all known globular clusters are being measured on photographs of small scale. It is hoped to determine integrated magnitudes and relative distances with considerably higher accuracy than has previously been attained. A redetermination of apparent diameters will also be made, and especial attention will be paid to the aberrant types of globular clusters. The new redetermination of the period-luminosity curve, which was made last year through a study of the Magellanic Clouds, helps to stabilize the work on clusters, and also provides a firmer basis for the measurement of the distances of star clouds and spiral nebulae.

The system of globular clusters outlines our own galactic system. Within the last two or three years we have become convinced that the spiral family of nebulae, which includes star clouds of the Magellanic type, consists of objects which are distinct outside systems. For many years the Harvard Observatory has investigated the nature, number, and distribution of these extra-galactic nebulae, largely because the Bruce refractor at Arequipa is a fairly potent instrument for the study of faint nebulous objects. We have found that among the thousands of nebulae there are doubles, multiples, and even large clusters of nebulae. During the past year it has been possible to make a survey of a cluster of large bright nebulae of the spiral family in the constellations Coma and Virgo. Photographs made by numerous telescopes were available for the investigation, which yielded not only integrated magnitudes of 103 nebulae in the group, but also gave results on form, angular and linear dimensions, and distribution in the sky. A preliminary estimate

indicates that this super-system of stellar systems is at a distance of some ten million light years, and its diameter is one-fifth the distance.

Further photometric studies of nebulae are under way; and one of the regular programs of the Bruce refractor is the accumulation of long exposure plates in order to complete to the eighteenth magnitude the survey of all the extra-galactic nebulae of the southern hemisphere. A very urgent need for astronomy is the analysis of these nebulous objects with a large modern reflecting telescope. Fortunately, it seems probable that such an instrument will soon be available for the southern station of the Observatory.

Spectrographic Investigations. The extension of the Henry Draper Catalogue, described in an earlier report, has been continued under Miss Cannon's supervision. About seven thousand stars have been classified, mainly in the Harvard A.G. zone from $+50°$ to $+55°$ and in the Helsingfors-Gotha A.G. zone from $+55°$ to $+60°$. In these two zones accurate positions of all A.G. stars have recently been obtained photographically at Yale down to the magnitude limit of the A.G. catalogue, which is about 9.2. Less than half of the zone stars appear in the Henry Draper Catalogue. It is possible, however, to obtain the spectra for nearly all of them from existing plates, thus providing important material for the discussion of spectra and motions. The classification is nearing completion, and the results will be published during the coming year.

In several regions along the Milky Way, especially in the Taurus region, several thousand faint stars have been classified, and the photographic magnitudes are now being determined.

The Draper 11-inch telescope, formerly at the Mandeville station, has been set up and put in operation at Cambridge during the year, its main project being the photometry of spectral lines. The 16-inch refractor and the 24-inch reflector, used with prisms and a series of apertured diaphragms, have also been involved in the survey of the depths and contour of prominent absorption lines in the spectra of stars of various classes. The researches are of basic importance in determining the structure of absorption lines and the nature of the atmospheres of stars. Miss Payne, Mr. Hogg, Dr. Dunham, and Mr. Chase will continue through the coming year the studies of stellar spectra — researches of an extremely varied character and of considerable significance in the interpretation of the behaviour of matter at high temperatures.

Mr. Davidovich continues his investigations of the spectra of

novae, and has made progress in the determination of their absolute luminosities from spectroscopic data. Miss Walton is assisting in an investigation of the relation between spectrum and period for Cepheid variables. Several other studies of a spectroscopic nature have been undertaken, but space is lacking for specific reference to them.

Photometric Studies. The photometric investigations have been numerous and varied in character. The partial bibliography at the end of the report indicates the scope of the work. Variable stars naturally play an important rôle. They have the full attention of three or four members of the staff, and are also studied with continued success by the members of the American Association of Variable Star Observers. The endowment of research on long period variable stars at the Harvard Observatory is highly desirable. Valuable contributions to our knowledge of an important stage in stellar evolution will come through the work of the variable star observers; and the extension of their program, especially to southern stars, is recognized by all astronomers as worthy of support.

Dr. Fisher has completed his study of the total lunar eclipse of August, 1924. Mr. Campbell has published the usual predictions and observations of long period variables, as well as several notes on variable stars of peculiar interest. One of the most important publications of the Observatory in recent years is the compilation, completed under Mr. Campbell's direction, of the maxima and minima of 272 long period variable stars. It represents a discussion of more than one hundred thousand observations.

Professor King has continued his photometric investigations, including measures for the color index of the Moon, reduction of the Nantucket eclipse plates for determining the distribution of the brightness in the solar corona, measures of earthlight on the lunar disk, and a study of extra-focal star images for the detection of a possible local cloud of absorbing material near the Sun. Further standards of magnitudes, for the Astrographic Catalogue, as determined by Miss Leavitt, have been published; and many special magnitude sequences have been set up in the study of variable stars, and also for the determination of photographic magnitudes in the Henry Draper Extension.

Miscellaneous. The usual coöperation with other observatories has continued, notably with the Astronomical Institute of Amsterdam, in a study of the structure of the Milky Way; with Princeton Observatory in the photographic determination of the position of

the Moon; with the observatories of Vassar College and Smith College in the study of proper motions; with Brown University and Bowdoin College in the photography of meteors, and with several observatories in the observation of long period variables.

There has been a healthy growth in additions to instrumental equipment and to the library, but no accessions deserving special comment.

Gifts from the American Academy of Arts and Sciences, the National Academy of Sciences, Mr. George R. Agassiz, and Professor Elihu Thomson have supported various special projects. The receipt of a bequest from the estate of Mr. George True Nealley of New York has enabled us to increase our shop facilities. A grant from the Milton fund has been mentioned above.

The studies of meteor photographs, and of fireballs, has been continued by Dr. Fisher. The special funds now available for his research are nearly exhausted, and some provision should be made for the continuation of the work. It appears that the study of meteors is more approachable by photographic methods, and more valuable for meteorological and astronomical investigations, than was recognized before the inception of Dr. Fisher's researches.

Publications. A series of twenty-two non-technical lectures, which were broadcast by nine members of the Observatory staff, has been published by the Observatory in a book of two hundred pages under the title "The Universe of Stars."

The titles of papers appearing in the Annals, Circulars, and Reprints during the past year are as follows:

H. A. **79**, Pt. 2. Maxima and Minima of Two Hundred and Seventy Two Long Period Variable Stars. Leon Campbell.

H. A. **82**, No. 5. The Location of One Hundred Points on the Planet Mars. William H. Pickering.

H. A. **85**, No. 8. Standards of Magnitude for the Astrographic Catalogue. Henrietta S. Leavitt.

H. A. **85**, No. 9. Photographic Determinations of the Position of the Moon. Charlotte Moore.

H. A. **87**. No. 1. Observations and Investigations made at the Blue Hill Meteorological Observatory in the year 1924. Alexander McAdie.

H. A. **100**, No. 2. The Henry Draper Extension. Annie J. Cannon.

H. C. 282. Note on the Theory of Pulsating Stars. Georges Lemaître.

H. C. 283. List of Addenda and Errata for the Catalogue of Proper Motion Stars Published in Lick Observatory Bulletin 344. Willem J. Luyten.

H. C. 284. The Total Lunar Eclipse of August 14, 1924. Willard J. Fisher.

H. C. 285. On the Distribution of Stars of Class F. Harlow Shapley and Helen E. Howarth.

H. C. 286. Harvard Results from Eclipse of January 24, 1925. Edward S. King.
H. C. 287. The Balmer Absorption Series in Stars of Class A. Cecilia Payne and Mary Howe.
H. C. 288. The Magellanic Clouds, VIII. Note on the Spectral Composition of the Foreground. Harlow Shapley and Margaret L. Walton.
H. C. 289. The Spectrum of Nova Pictoris 1925 on May 28. Paul Davidovich.
H. C. 290. Long Period Variables, Predicted Maxima and Minima, 1926. Leon Campbell.
H. C. 291. Note on Ionization in Giant and Dwarf Stars. Henry Norris Russell.
H. C. 292. Variability of the "Iron Star," XX Ophiuchi. Harlow Shapley and Ida E. Woods.
H. C. 293. Notes on Proper Motions. Willem J. Luyten.
H. C. 294. A Study of a Cluster of Bright Spiral Nebulae. Harlow Shapley and Adelaide Ames.
H. C. 295. On the Spectrum and Luminosity of Nova Pictoris 1925.4. Paul Davidovich.
H. C. 296. Observed Maxima and Minima of Variable Stars for 1925. Leon Campbell.
Reprint 22. The Frequency Distribution of Some Measured Parallaxes and of the Parallaxes Themselves. Edwin B. Wilson and Willem J. Luyten.
Reprint 23. Conditions in South Africa for Astronomical Observations. Solon I. Bailey.
Reprint 24. On Some Problems Connected with the Luminosity Law. Willem J. Luyten.
Reprint 25. The Magellanic Clouds. Harlow Shapley.
Reprint 26. Joel Hastings Metcalf. Solon I. Bailey.
Reprint 27. Harvard Eclipse Observations on January 24, 1925. Edward S. King.
Reprint 28. On the Distribution of Intensity in Stellar Absorption Lines. Cecilia H. Payne and Harlow Shapley.
Reprint 29. Radio Talks from the Harvard Observatory. Leon Campbell, Solon I. Bailey, Cecilia H. Payne.
Reprint 30. The Properties of Stars in the Solar Neighborhood. Willem J. Luyten.
Reprint 31. The Fireballs of November 15 and December 29, 1925. Willard J. Fisher.
Reprint 32. Island Universes. Willem J. Luyten.

A series of Announcement Cards (supplementing the telegraphic service) has been inaugurated to carry immediate news of comets, asteroids, and similar matters.

Sixty-three articles and notes by members of the staff have appeared during the year in the Observatory's Bulletins. Listed below are the titles of some of the more important of these papers, representing the work of Campbell, Cunningham, Miss Cannon, Davidovich, Miss Fairfield, Fisher, Miss Harwood, Jordan, Luyten, Miss Payne, Shapley, Miss Woods.

H. B. 825. Twenty-Five New Variable Stars.

H. B. 826. Wolf's Nova in Aquila (Nova Aquilae 1925.7). New Variable Resembling a Nova.

H. B. 827. Daylight Meteor, November 15, 1925.

H. B. 831. Irregular Variables of Spectral Class K.

H. B. 833. Fireballs of December 29, 1925.

H. B. 834. S Corvi. Wolf-Rayet Spectrum with Absorption Lines. Surface Photometry of Jupiter with the Harvard 60-inch Reflector. Proper Motion of a Red Dwarf. Concerning Dark Nebulosity surrounding X Cancri. Fifty New Variable Stars in the Southern Milky Way.

H. B. 835. Proper Motion Star with Variable Bright Lines. On Nitrogen in the Spectra of the Sun and Stars. Oxygen in Stellar Atmospheres. The Photographic Energy Curves of the Spectrum of Nova Pictoris 1925.4.

H. B. 836. Nova in N.G.C. 4303. Sequence of Comparison Stars for Nova Pictoris 1925.4. Eros (433). On the Astrophysical Behaviour of certain Iron Lines. Yellow Emission Bands for Seven Class O Stars.

H. B. 837. Peculiar Spectra. Distribution of Intensity in Bright Hydrogen Lines of γ Cassiopeiae. Comparison of the Spectra of η Carinae and Nova Pictoris.

H. B. 838. On the Relative Diameters of Spiral and Elliptical Nebulae. Note on the Relative Number of Spiral and Elliptical Nebulae. The Long Period Variable S Sculptoris. Twenty-five New Variable Stars in the Southern Milky Way.

HARLOW SHAPLEY, *Director.*

EIGHTY-SECOND

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1927

BY

HARLOW SHAPLEY

STEWARD OBSERVATORY
TUCSON, ARIZ.

CAMBRIDGE, MASSACHUSETTS
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1928

STEWARD OBSERVATORY
TUCSON, ARIZONA

THE OBSERVATORY

To the President of the University:

Sir, — Progress has been made in the Observatory's work on proper motions, globular clusters, nebulae, variable stars, meteors, and spectrum analysis and classification, but the outstanding events of the past year are the transfer of the Boyden Station to South Africa and the provision of a large reflector for the southern hemisphere. Not for three decades has the Observatory made such substantial advance in material equipment as is represented in the present enlargement of the southern station.

The new 60-inch reflector. The Harvard Observatory has carried on fundamental surveying work in the southern skies for thirty-seven years, attacking the numerous problems in a comprehensive manner, but seldom analytically. For example, the visual brightness, spectral classification, and variations in light have been studied for thousands of stars; a score of new stars have been found on plates made at the Boyden Station; some ten thousand nebulae have been discovered; and surveys of double stars, star clouds, gaseous nebulae, and star clusters have been products of the systematic work with the several photographic refractors. But searching analyses of special objects such as the Magellanic Clouds, globular clusters, gaseous nebulae, and individual stars have generally been impossible. The rapid photographic refractors and patrol cameras are suitable for the fundamental work and their use will be continued unabated, but a large well-equipped reflecting telescope is necessary for the special analytical studies.

Generous gifts to the Observatory this last year from the International Education Board and from Harvard University have provided for the transfer of the Boyden Station from Peru to South Africa and for the construction and endowment of a 60-inch reflecting telescope of modern design. It will be the largest telescope in operation in the southern hemisphere. One of the Common mirrors already in the possession of the Observatory, refigured to the necessary extent, will be the main optical part of the telescope. The mounting is to be of the two pier type, and will be arranged for use in both the Newtonian and modified Cassegrainian combinations. The construction of the mounting, which is in the hands of J. W.

Fecker, of Pittsburgh, successor to Brashear and McDowell, is well advanced.

Other new telescopic equipment. The Bruce 24-inch telescope has in past years been one of the most productive instruments in the southern hemisphere despite its poor mounting. It has produced the plates for the studies of the Magellanic Clouds, southern nebulae, Milky Way structure, and the star clusters. Its removal from Arequipa affords the opportunity for a new mounting of the two pier type. Mr. Fecker has received the contract also for this work, which is nearly completed. With the new mounting the telescope will be used in the Observatory's extensive programs on proper motions and faint nebulae.

The new funds mentioned above also provide a mounting for the Metcalf 10-inch triplet, which in the past has been accommodated on the mounting of the 8-inch doublet. The new mounting has been purchased and tested, and will soon be installed in South Africa. This telescope is one of the important features in the study of variable stars in the Milky Way.

Special gifts from Mr. George R. Agassiz and Mr. Gerard Swope have provided for the making of two 3-inch lenses of the new Ross type, to replace lenses now used in the sky patrol. The lenses have been constructed, and if they prove on testing to be as satisfactory as is anticipated, we may look forward to a new epoch in the effectiveness of the Harvard sky patrol. Greater speed, larger scale, and better images over the whole field seem to be assured.

The South African site of the Boyden Station. The moving from Arequipa, Peru, to Bloemfontein, in the Orange Free State, Union of South Africa, was begun in November 1926. The telescopes, library, and incidental equipment were shipped to Bloemfontein by way of New York in February of this year and in July Dr. Paraskevopoulos, superintendent of the southern station, and Mrs. Paraskevopoulos arrived in South Africa.

The new permanent site of the station has now been located on a low kopje at Mazelspoort, the water works settlement of Bloemfontein, fourteen miles northeast of that city. The altitude is approximately 4,500 feet, the longitude $1^h\ 45^m\ 37^s$ east, and the latitude 29°.2 south. The Harvard Observatory is indebted to Professor R. A. Rossiter, of the University of Michigan, for assistance and advice in connection with the inspection of observatory sites. We are particularly grateful for the coöperation of the Government of the City of Bloemfontein. The city has shown much interest in our station, and, in the building of roads, the laying of water,

power, and telephone lines, the provision of expert engineering service, and in other important ways has helped us financially to the extent of several thousand dollars. All available evidence indicates that the new site will be superior to that at Arequipa, especially in the avoidance of an unbroken cloudy season, which greatly hindered the work in Peru from December to April.

Pending the building of a road to "Harvard Kopje" and the construction of permanent buildings, a temporary installation of two telescopes has been made at Mazelspoort. Observations were resumed in September on the southern sky patrol and on southern galactic variable stars.

New Research Fellowship. A long standing need of the Observatory has been met this year through the endowment on a generous scale by Mr. George R. Agassiz of a research fellowship for an advanced student in astronomy. The first holder of the fellowship is Mr. Frank S. Hogg, B.A. (Toronto), M.A. (Harvard), whose researches in spectroscopy are referred to below.

Synopsis of the Year's Scientific Results

Space prohibits the description of the Observatory's problems or a general account of any phase of the researches in progress. The annual bibliography has grown too large for inclusion in the report, as in former years. It seems advisable to give here only a brief summary of the results of the year's investigations.

A. *The Discovery, Classification, and Measurement of Nebulae*

1. Approximately eight thousand new nebulae have been found on photographs, averaging about three hours exposure, made at Arequipa with the 24-inch Bruce refractor. Two-thirds of these nebulae are in the southern hemisphere, and nearly all belong to the extra-galactic class.

2. A new descriptive classification of nebulae, in which the form and central concentration of the photographic image are the salient features, has been formulated. Earlier systems of classification of extra-galactic nebulae have proved unsuitable for the thousands of faint objects shown on the Bruce photographs.

3. The detailed study of the region of the Coma-Virgo cloud of nebulae has been continued by Miss Ames who is making a catalogue that not only will include the positions, angular dimensions, and classifications of more than two thousand nebulae, mostly new, but will also contain integrated magnitudes on a fairly reliable scale. Probably only the two hundred brightest nebulae belong to

the Coma-Virgo cloud; the other objects, fainter in general than the sixteenth magnitude, are much more remote, possibly at distances of the order of one hundred million light years.

4. An examination by Dr. Shapley of long exposure Harvard photographs failed to verify the existence of the many dark nebulosities in high galactic latitudes, suspected by Lundmark and Melotte from an examination of Franklin-Adams plates; but an obscuration near μ_1 Serpentis, galactic latitude 35°, is confirmed (H.B. 844). A large unrecorded diffuse nebulosity in Centaurus and Musca, near the Coal Sack, is shown on suitably exposed plates from Arequipa. Its diameter is 2°.5 (H.B. 843).

B. *Meteors and Fireballs*

5. A study by Dr. Fisher of the ratio of iron to stone in meteorite falls (H.B. 845) yields the result 2.5, which is regarded as an indication of the ratio of iron to stone in the dark matter of interplanetary and interstellar space. The ratio of iron to stone in the Earth is probably about 4.5. The total number of "falls" and "finds" of all sorts was 849 up to the end of 1922, with a total weight of at least 120 tons.

6. The remarkable shower of fireballs which appeared within a few minutes of 8 P.M., E.S.T., on August 10, 1927, was studied by Dr. Fisher. Twenty-six meteors were seen, passing for the most part over southern New England (H.B. 851).

7. The systematic survey of Harvard photographs under the auspices of the J. Lawrence Smith Fund of the National Academy of Sciences has been practically completed, yielding a total of 346 meteor trains (including those previously known on Harvard plates). This large collection of material is now being studied.

8. A grant from the Milton Fund of Harvard University has permitted Dr. Fisher to initiate experiments on lenses and cameras most suitable for meteor photography.

C. *Variable Stars*

9. More than seventy notes on variable stars have appeared during the year in Harvard Observatory publications.

10. Active work has been continued on the program of Milky Way variables, which is partly supported by a grant from the Milton Fund. Seven workers are engaged in the examination of plates in 190 Milky Way regions and 36 non-galactic fields. Several hundred variable stars have been detected (mainly by Miss Swope,

Miss Woods, and Miss Gill), for which publication is deferred until the regions under study have been more fully examined.

11. Fifteen new variable stars have been published, bringing the number of Harvard Variables to 4010. Over a hundred and fifty other new variables will be announced in Harvard Bulletins already in press or in preparation. Seventy-two were found by Dr. Luyten with the blink microscope, and seventy-five by Miss Woods in her systematic examination of plates. The lists include twenty-six long period variables, two Cepheids, two eclipsing stars, three stars of the R Coronae type, one of the RV Tauri type, and five novae. One of the novae and one of the R Coronae stars are in the Large Magellanic Cloud, and therefore of exceptional interest. Several irregular variables are also announced — one in the Andromeda Nebula. The new variables represent the work of Professor Gerasimovič, research associate from the University of Kharkow, Miss Harwood, of the Maria Mitchell Observatory, Dr. Luyten, Dr. Paraskevopoulos, Miss Swope, Miss Walton, and Miss Woods.

12. Eclipsing stars have been studied photographically. Mr. Waterfield has published light curves for V Leporis, UW Virginis, ZZ Sagittarii, Z Normae, DW Sagittarii, and RV Telescopii; Miss Woods has derived the light curve of W Ursae Minoris, and Professor Gerasimovič has obtained light curve and orbit for SX Cassiopeiae. Orbits have been computed by Mrs. Shapley for X Trianguli, V Leporis, FP Carinae, W Ursae Minoris, ZZ Sagittarii, TT Hydrae, and UW Virginis. The last of these stars has a remarkably large range at primary minimum.

13. Visual data on southern long period variables have been assembled and discussed by Mr. Campbell for T Apodis, T Phoenicis, U Tucanae, R Reticuli, R Chamaeleontis, R Carinae, Z Velorum, U Centauri, RR and RS Scorpii, S Tucanae, and V Sculptoris. Dr. Shapley and Mr. Waterfield have outlined a scheme for the photographic study of long period variable stars on Harvard plates, and published light curves for TW and TU Centauri (H.R. 41). Dr. Luyten has derived light elements for the long period variables H.V. 884 and YY Scorpii. A spectrographic study of Mira Ceti is described in Section F.

14. Cepheid variables have been the subject of several extensive investigations; the period-spectrum relation, the resulting period-luminosity curve, and certain problems connected with cluster variables are mentioned in Sections F and G. The fourth magnitude star β Doradus has been shown to be a normal Cepheid variable (H.C. 313). A revision has been made by Dr. Shapley and

Miss Roper of the periods of seventy-three Cepheid variables in the cluster Messier 5, and the variables in Messier 22 have been investigated by Miss Swope.

15. An accurate determination of the median photographic magnitudes of fifty Cepheid variables by Miss Walton has formed the basis of estimates of their distances (H.B. 845).

16. Studies of several individual Cepheid variables of long period have been made by Professor Gerasimovič, and elements and light curves have been derived for SV Vulpeculae, CG Sagittarii (which is at a distance of forty kiloparsecs), SZ Cassiopeiae, and RS Puppis.

17. The "quasi β Lyrae" type of variable has been studied by Professor Gerasimovič, who published detailed discussions of SS Geminorum, TT and TX Ophiuchi, H.V. 4002, recently discovered by Miss Harwood, and V Vulpeculae. AC Herculis, for which Mr. Waterfield publishes a light curve, is a star of similar type. This, the first systematic study of a kind of variation that is hard to interpret, may suggest connecting links between variation of the Cepheid and long period types. The stars RU Aquarii and Z Leonis, examined in the course of his study of semi-regular variables by Professor Gerasimovič, are found to undergo variations hitherto unduplicated.

18. Changes of period have been found for the eclipsing star SW Lacertae by Mr. Campbell, by Mr. Waterfield for the cluster variable RR Geminorum, and by Professor Gerasimovič for the semi-regular variable V Vulpeculae. Corrected periods have been derived by Mr. Campbell for U Cephei, and by Mr. Waterfield for RZ Librae. Miss Sawyer finds that TX Scorpii is not variable.

19. Observations and possible interpretations of the peculiar variable RT Serpentis, which appeared in 1909 and is now slowly fading, are summarized by Dr. Shapley in Harvard Bulletin 851.

20. Professor Hertzsprung, of Leiden University, during a seven months' visit to the Harvard Observatory, made 11,000 estimates of the magnitudes of short period variables. His researches bear on the important discovery previously made by him of the systematic relation of form of light curve to period length among typical Cepheid variables. A peculiar object of very short duration, photographed on a Harvard plate, is described by him in Harvard Bulletin 845.

21. A catalogue of long period variable stars, begun at Harvard by Professor Townley, of Stanford University, is nearing completion by Mr. Campbell and Miss Cannon, and will soon be published.

22. In addition to the usual Harvard Circulars predicting and summarizing the maxima and minima of long period variables, a compilation has been published by Mr. Campbell of the observations for 1926 on three irregular variables of the SS Cygni type, four of the R Coronae Borealis type, and R Scuti and R Orionis. The bimonthly predictions for long period variables, based on the observations of the A.A.V.S.O., have been continued in the Bulletins as in previous years.

23. A hundred observers have sent more than thirty-two thousand observations to the Observatory during the year. The A.A.V.S.O. has been responsible for about eighteen thousand of these, and the French Variable Star Observers for about fourteen thousand. Some other observations have come from individuals, and from other observatories. As in previous years, all the contributed observations have been plotted, entered in ten-day ledgers, and used in deriving the predicted and observed dates of maxima and minima that are published by the Observatory.

D. *Proper Motions*

24. Of the total number of four hundred pairs of old and recent Bache plates taken for proper motion work, 230 had been examined in the blink-microscope before September 30, 1926, and the remaining 180 pairs have now been analyzed. The total number of objects marked by Dr. Luyten on these plates has been brought up to 2500. Allowing for the overlapping of the plates and for objects already known, it is expected that from seven hundred to a thousand new proper motions will be measured.

25. A first list of proper motions found from Bache plates was published as Harvard Circular 310. Subsequent surveys of proper motion with the blink-microscope have been confined to plates taken with the 24–inch Bruce telescope. A set of plates taken with this instrument, mainly between 1896 and 1904, showing stars down to the sixteenth magnitude and covering practically the entire southern sky, will provide excellent material for a proper motion survey of the southern hemisphere as soon as new plates have been taken. Only a small number of suitable pairs is available at present, of which thirty have been examined during the past year; some two thousand proper motion stars, mainly between magnitudes 12 and 16, have been found.

26. Proper motions of thirty-one stars, found on Bruce plates centered on the Orion Nebula and the Hyades, have been published in Harvard Circular 310.

27. The largest proper motion thus far discovered, 1″.66 annually, is that of a star of magnitude 14.5 in the region of η Carinae (H.B. 845). Sixteen pairs with common proper motion have been measured (H.B. 852).

28. Proper motions of eleven cluster type variables have been determined from plates in the Harvard collection (H.B. 847), and the proper motion of Nova Pictoris has been found to be 0″.05 in 247° (H.B. 852).

29. On a pair of plates centered on the Large Magellanic Cloud some five hundred proper motion stars brighter than magnitude 15.5 have been found within an area of sixteen square degrees. The measurement of these proper motions is almost completed.

30. The work on proper motions is supported in part by a grant from the Gould Fund of the National Academy of Sciences.

E. *Star Clusters*

31. A classification based on the degree of central concentration has been devised for globular star clusters, and has been applied by Dr. Shapley and Miss Sawyer to all known globular systems (H.B. 849). The angular diameters and integrated photographic magnitudes have been measured on many photographs of several special series (H.B. 848, 851), as a preliminary step to the determination of the distances and distribution of globular clusters and the measurement of the size of the Milky Way. The forms and orientations, so far as determinate, have also been derived from Harvard plates.

32. The bright galactic cluster N.G.C. 6231 has been measured for proper motion by Professor Priscilla Fairfield, of Smith College (H.B. 843); a general photometric survey, including an estimate of the distance, has been made by Dr. Shapley and Miss Sawyer (H.B. 846).

33. The distance of Messier 22, the brightest and nearest globular cluster visible from northern observatories, has been determined by Dr. Shapley to be twenty-one thousand light years; this value is based on a study of the bright stars, supplemented by new investigations of the cluster type variables by Miss Swope (H.B. 848).

34. Miss Roper has assisted in a study of the stars in the more distant globular cluster Messier 5; results have been obtained bearing on the uniformity of periods of about fifty variable stars throughout intervals of six thousand maxima (twenty-eight years) (H.B. 851), and bearing on the constancy of brightness of presumably non-variable stars. The work, begun at Mount Wilson, has been in progress intermittently for ten years.

F. *Spectroscopic Researches*

35. During the year 20,091 spectra have been classified, comprising those of 3650 stars from the catalogues of the Astronomische Gesellschaft between $+50°$ and $+60°$, of 4191 stars at the North Galactic Pole, and of 12,250 stars in the Taurus-Monoceros regions of the Milky Way. The total number of spectra now classified by Miss Cannon at Harvard is 256,941. The fourth section of the Henry Draper Extension, now in press, brings the number of published classifications up to 240,500.

36. Wave lengths and identifications for more than five hundred lines in the spectra of γ Cygni and δ Canis Majoris have been derived by Miss Payne and Mr. Chase (H.C. 300); all the stronger lines of ionized lanthanum, ionized zirconium, ionized yttrium, and ionized euronium are found (H.B. 841). A detailed analysis of the spectrum of α Persei, partly based on long dispersion Harvard plates, has been made by Dr. Dunham. Miss Payne finds all the stronger lines of the atom of ionized vanadium present in the solar spectrum (H.B. 841).

37. The spectral changes of seventy of the brighter Cepheid variables have been discussed by Dr. Shapley and Miss Walton. The ranges in spectral class vary between twelve and three spectral subdivisions. The range in spectrum is not apparently related to the median spectral class, nor to the length of period (H.C. 313). A strong correlation of median spectral class with length of period is shown. An important application of the result is the standardization of spectral criteria of luminosity for very bright stars.

38. Several investigators have devoted a large part of their time to the development of spectrophotometric method. The calibration of plates by the use of standard apertures has been put on a working basis by Miss Payne and Mr. Hogg (H.C. 301). Another method of plate standardization by photographing simultaneously several stars of known magnitudes was first applied by them to stars of the same spectral class, notably the brighter Pleiades (H.C. 301), but was extended by Mr. Hogg to include stars of all spectral classes (H.C. 309), and forms the basis of his program of standard close pairs of bright stars with suitable magnitude intervals, conveniently distributed over the sky. Methods of laboratory calibration were developed by Dr. Dunham (H.B. 853). Miss Payne has found the use of standard line depths applicable in some problems.

39. Spectrophotometric studies of several stars have been published. Miss Payne and Mr. Hogg discuss line depths for the Pleiades, and relate them to the surrounding nebulosity (H.C.

303); Dr. Dunham gives preliminary results of a study of stars of Class A (H.B. 853); the variations of Mira Ceti were followed by Miss Payne and Mr. Hogg, who find that the emission lines never contribute more than a tenth of a magnitude to the star's light, and the absorption bands divert about twenty per cent (H.C. 308). Detailed spectrophotometric analyses are made by Miss Payne of nine other bright stars (H.C. 305, 306), and the application to the study of temperature and luminosity is briefly discussed (H.C. 307).

40. From a study of forty of the brighter Pleiades, Mr. Hogg derives their temperatures and concludes that the assumption of black body radiation is satisfactory for all the stars concerned (H.C. 309). Miss Payne, in a similar study of seventeen stars near the open cluster N.G.C. 6231, finds that the energy distribution in the spectra of the Wolf-Rayet stars does not fit satisfactorily with black body assumptions; if energy temperatures can be assigned to these stars at all, they are sensibly cooler than normal stars of Class B0 (H.B. 845). She proposes to express the energy distribution in stellar spectra in terms of "color magnitudes."

41. Numerous investigations have dealt with emission lines in stellar spectra. The connection between absorption and emission lines has been discussed by Mr. Davidovich, who notes the tendency of emission to occur at the red end of a series, and distinguishes central emission and emission wings, regarding the latter as indicative of motion in the stellar atmosphere (H.B. 846). Miss Payne and Mr. Hogg consider in their study of the Pleiades that the weakening of $H\beta$ as compared with $H\gamma$ is an effect of incipient central emission (H.C. 303).

42. Twelve southern B stars showing unrecorded bright lines have been found by Miss Payne (H.B. 846). Professor Gerasimovič adds seven stars to the number already known that have diffuse bright lines of ionized iron (H.B. 851).

43. The southern stars of Class O, both of absorption and Wolf-Rayet type, have been completely re-observed with increased dispersion, and their spectra described in detail (H.B. 842, 843). Miss Payne has found ten stars hitherto unrecognized as O stars, including one of Wolf-Rayet type, among the early B stars — fewer than was expected. It is possible that Class O could profitably be redefined to include some of the early B stars (H.B. 846).

44. The detailed analysis of the spectrum of Nova Pictoris was continued by Mr. Davidovich; the main part of his investigation is still unpublished. Some of the major changes in the spectrum be-

tween December 1925 and October 1926 are described in Harvard Bulletin 839.

G. *Theoretical Researches*

45. In a study of the distance of the Sun from the galactic plane, by Professor Gerasimovič and Dr. Luyten, a value of +33 parsecs, with a mean error not greater than three parsecs, is deduced (H.R. 37). The somewhat different result derived by Charlier for the Class B stars, and a determination by him of the coördinates of the center of the system of B stars, are criticized by Dr. Shapley on the ground that Charlier's material is not homogeneous (H.B. 846).

46. From an investigation of the luminosities of stars of Class B3, Professor Gerasimovič concludes that stars showing emission lines are distinctly brighter than those that have only absorption lines. The conclusion is qualitatively supported by data, on all classes from O to B5, taken from moving clusters. Thus it appears that among the B stars the higher luminosities are associated with the lower temperatures, a result recalling the decrease of temperature in passing from dwarf to giant among the cooler stars (H.B. 849).

47. The observed period-spectrum relation for *galactic* Cepheid variables is shown by Dr. Shapley to lead directly to a period-luminosity curve that is in very close agreement with the period-luminosity curves derived from clusters and star clouds.

48. The cluster type variables do not show a change of median absolute magnitude, color index, or spectral class with period. The interpretation of this fact cannot involve differences in mean density and dimensions, or in mass. Dr. Shapley suggests (H.C. 315) that the anomaly is connected with important nuclear changes in the stars, associated perhaps with the critical position of the cluster variables in the spectral series, between the giants and the main sequence.

49. For the Saha formula giving the degree of ionization in a stellar atmosphere, Professor Gerasimovič has evaluated the correction that must be applied for small deviations from thermodynamic equilibrium; the correction is of importance in the uppermost photospheric layers, and for stars with extended atmospheres its effects may be considerable (H.R. 36). The alternative formula suggested by Pannekoek would be considerably modified if a different functional relation were assumed between the probability of ionization and the frequency (H.B. 841).

50. The theory of the application of the simple ionization formula to the interpretation of absolute magnitude effects is discussed,

illustrated, and applied by Miss Payne. The relative intensities of neutral and ionized lines of the same atom may be used, if the temperature is known, to derive a value of the pressure in the reversing layer. Preliminary results, derived from visual estimates for stars of Class cF8, are of a plausible order (H.R. 33, 34).

51. A general examination of the spectroscopic absolute magnitude effect, based on the lines of iron and ionized strontium, throughout the spectral sequence, has been made by Professor Gerasimovič. Stellar temperature scales are calculated for giants and dwarfs, and it is found that giant stars of class earlier than about F8 are hotter than the corresponding dwarfs (H.B. 843).

52. Professor Gerasimovič has adapted the theory of ionization to the analysis of nebular conditions, discussing a planetary nebula with a hot central star. The electron temperature, which is a function only of the optical thickness of the nebular gas and of the temperature of the star, may be between 2,000° and 25,000°. Stars cooler than Class B2 cannot form the nuclei of planetaries. An enhanced bright line spectrum cannot be formed around a star of Class Md if the envelope is in a steady state — a result with applications in the spectroscopic interpretation of long period variables (H. R. 38).

53. It is shown by Professor Gerasimovič that the ionizing effect of penetrating radiation on stellar atmospheres must in general be negligible. Within diffuse nebulae, however, and in the atmospheres of supergiant M stars, conditions are favorable to the formation of relatively strong local fields of penetrating radiation and the ionizing effect may then be sensible (H.R. 39).

54. A method of calibrating objective gratings for photometric use is described and illustrated by Professor Hertzsprung in Harvard Bulletin 845.

55. Dr. Fisher has been led by the noticeable area of shower radiants, the straightness of meteor paths, the observed orientation of meteorites, and the flicker often observed and photographed for meteors, to an interpretation in terms of the dynamics of a spinning projectile moving in a resisting medium.

H. *Miscellaneous*

56. Professor King and Miss Harwood have completed a detailed photometric study of the distribution of light in the corona photographed at the total solar eclipse of January 24, 1925, at the Maria Mitchell Observatory, Nantucket (H.C. 312).

57. From a photometric study of a number of bright stars, Professor King concludes that a local cloud of absorbing matter may be responsible for the preferential reddening of stars that are nearer than a hundred light years (H.C. 299).

58. Dr. Paraskevopoulos has measured the integrated brightness of the Small Magellanic Cloud, photographing it out of focus with lenses an inch or less in aperture. The integrated apparent magnitude is +2.3, corresponding to an absolute photographic magnitude of −15.7.

59. The Observatory's library has been increased by 1825 books and pamphlets, bringing the total number of accessions to 67,180.

60. The publications of the Observatory during the year comprised twenty Circulars, eleven Bulletins containing 120 contributions, and ten Reprints from various scientific periodicals. Twenty-five announcement Cards were issued.

61. During the year 3600 plates were made with the telescopes at Cambridge, under the general direction of Professor King, and 450 plates were made at Arequipa and Bloemfontein.

HARLOW SHAPLEY, *Director.*

EIGHTY-THIRD

ANNUAL REPORT

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THE ASTRONOMICAL OBSERVATORY

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HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1928

BY

HARLOW SHAPLEY

CAMBRIDGE, MASSACHUSETTS
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1929

THE OBSERVATORY

To the President of the University:

Sir, — The inauguration at the Observatory of formal graduate studies in astronomy is a significant advance in the Observatory's development. Heretofore Harvard has played a minor part in the training of teachers and investigators in astronomy, and the Observatory itself has suffered from the lack of competently trained students directly familiar with its methods and problems. Professor Harry H. Plaskett has been called from the Dominion Astrophysical Observatory at Victoria to take a leading part in the direction of the researches of advanced students and in the instruction in theoretical astrophysics. He is widely known for his own investigations in spectrum analysis and is therefore a valuable adviser in the Observatory's many spectroscopic researches. A new course in the theory and practice of astronomical observations has been inaugurated at the Observatory with six members of the staff participating in the instruction in their respective fields. Research courses are now offered in the fields of stellar systems, analysis of spectra, stellar statistics, meteors, and photometry.

Good progress has been made during the past year on the more important programs of the Observatory, especially in the discovery and measurement of large proper motions, the cataloguing of long period variables, the discovery, measurement, and description of extra-galactic nebulae, the measurement and interpretation of spectral line contours, and the numerous studies of variable stars.

The construction of residence, offices, garage, and telescope buildings on Harvard Kopje at Bloemfontein is well under way. New mountings for the 10-inch Metcalf and for the 24-inch Bruce telescopes have been shipped to South Africa during the year. A new Ross lens has been made and tested. Work on the mirror and mounting for the new 60-inch telescope is progressing satisfactorily, and before the end of next year we hope the telescope will be at Bloemfontein.

Professor Luyten and Mr. Waterfield have gone to South Africa during the year, the former on a fellowship from the Guggenheim Foundation for the study of proper motions of southern stars with the Bruce telescope.

Dr. Otto Struve of the Yerkes Observatory, Dr. Alexander Vyssotsky of the University of Virginia, and Dr. Leon Hufnagel of Poland have each spent a part of the year at the Observatory in spectroscopic researches.

A synopsis of the year's scientific results is given below in the place of a general account of specific problems.

A. *Variable Stars*

1. In the investigation of Milky Way variables, four hundred and twenty-two variable stars have been discovered and published. Seventeen Innes variables have also been rediscovered. Most of these variable stars are of long period, and for a large number of them approximate elements are already determined by Miss Swope, Dr. Luyten, and Professor Gerasimovič.

2. In continuation of his study of eclipsing stars, Mr. Waterfield has determined the photographic light curves of UU Ophiuchi, W Volantis, and T Circini (H.B. 852, 853, 855). The light curve of H.V. 4159 was determined by Miss Woods, and the orbit of this star computed by Mrs. Shapley (H.B. 854). Mr. Campbell gives the period and visual light curve of the short period eclipsing star B.D. $-20°$ 2009 (H.B. 858). A new eclipsing star is announced by Mr. Waterfield in Harvard Bulletin 854, and one with a period of 732 days, or, less probably, of 244 days, has been found by Dr. Luyten (H.B. 852).

3. The Harvard Catalogue of Long Period Variables, compiled by Professor Townley, Miss Cannon, and Mr. Campbell, has been published by the Observatory during the year (H.A., **79**, No. 3). It is based on the detailed bibliography that has been kept for many years by Miss Cannon for all published variable stars, and contains 1769 stars that can be assigned with a certain degree of confidence to the long period class. For eleven hundred of them the periods are known, for 33 per cent the spectra have been classified, and for 27 per cent the class of light curve is known. The catalogue is more than a compilation, for it contains classifications by Miss Cannon of all available spectra, and serves for the study of the spectral variations. The material is the most extensive of its kind in existence, and forms the basis of several important statistical discussions.

4. Elements have been determined and published for ninety-five long period variables, in addition to those for stars discovered and announced during the year. They are for the most part the result of a systematic study under the direction of Miss Payne of

the photographic plates of long period variables of unknown period — a research outlined in Harvard Reprint 41 by Dr. Shapley and Mr. Waterfield.

5. The relations of period, spectral class, range, and apparent magnitude have been discussed by Miss Cannon and Mr. Campbell on the basis of the new catalogue. The most significant features of the discussion are the relation between period and spectrum, and the frequency curve for period. Spectrum and range, period and range, and period and brightness are not strongly correlated.

6. The period-spectrum relation for long period variables is discussed by Dr. Shapley (H.B. 861) in its bearing on the relationship that undoubtedly exists between the long period variables and the Cepheids. He points out that the similarities between the two classes of stars are intrinsic, and their differences are mainly incidental to the conditions that depend on different stages of the same type of phenomenon in two classes of stars.

7. Professor Gerasimovič has continued his detailed study of the RV Tauri class, and discusses the variations of V Vulpeculae (H.C. 321), and the light curve (H. C. 323) and changing period (H.C. 333) of R Scuti. He notes AR Sagittarii as an undoubted member of the RV Tauri class (H.B. 857). The variable Z Ursae Majoris appears to be a star of a type intermediate between the long period variable and the RV Tauri star, sometimes displaying the one kind of variation, sometimes the other (H.B. 856).

8. Still more remarkable is the type of variation displayed by UU Herculis, which has two distinct but commensurable periods (H.B. 857). Professor Gerasimovič also finds, in collaboration with Miss Walton, that Z Cancri has three distinct but commensurable periods (H.B. 862).

9. Three R Coronae type variables are announced; one was found by Dr. Luyten with the blink microscope (H.B. 852), and two, previously supposed to be typical long period variables, are described by Miss Payne in Harvard Bulletin 861. Observations of the R Coronae type variables already known are continued by members of the A.A.V.S.O.; the light of R Coronae Borealis has been constant throughout the year, and S Apodis has decreased continuously in brightness.

10. Several interesting irregular variables are announced, notably one in the Andromeda nebula, pointed out by Dr. Luyten (H.B. 859) to be of absolute magnitude about -7.5, if not a foreground star. The two stars TV Andromedae and W Apodis, pre-

viously supposed to be semi-regular and eclipsing stars, are found respectively by Professor Gerasimovič and Mr. Waterfield to vary irregularly (H.B. 852, 854). The supposed long period variable FN Sagittarii is found by Miss Payne to resemble a nova of small range (H.B. 861). Other interesting irregular variables, found by Dr. Luyten with the blink microscope, are described in Harvard Bulletin 852.

11. The variations of ϵ Aurigae are discussed by Dr. Shapley. The apparent drop (towards the expected minimum) that occurred early in the year appears to be a part of the normal variation of its maximum light. A period of about 355 days is indicated for the variation of small range (H.B. 858).

12. The usual summaries of observed maxima and minima for long period variables (H.C. 329) and irregular variables (H.C. 330) have been published by Mr. Campbell. Predictions for the year (H.C. 320), and the regular bimonthly predictions, have also been issued.

13. Nearly 44,000 observations of variable stars have been contributed to the Observatory by more than a hundred observers — 38 per cent more than were received last year. The observations are almost equally divided between the A.A.V.S.O. and the French Variable Star Association.

B. *Proper Motions*

14. The proper motions of eighteen hundred stars, discovered with the blink microscope, have been measured and published by Dr. Luyten. Five hundred of these stars are in front of the Large Magellanic Cloud. The distribution of their motions is striking. There appears to be a number of stars of abnormal velocity in the region.

15. Dr. Fairfield has published the proper motions of 213 southern stars of Class M (H.C. 322). There is no evidence in these data of the existence of any M star of absolute magnitude intermediate between giant and dwarf.

16. Attention is called by Dr. Luyten to an A star and a B star, both of large proper motion (H.B. 852, 858). He also reports on a star of Class K, which has an absolute magnitude of 12.3, and is therefore an extreme dwarf (H.B. 861).

17. The proper motion of Nova Pictoris, measured by Dr. Luyten, is consistent with the absolute magnitude +7 before the outburst (H.B. 852).

C. *Meteors and Fireballs*

18. The meteor trails photographed on Harvard plates are under study by Dr. Fisher, the searching of the plates having been completed. In addition to producing a large amount of material on meteors, the search has important bearings on the problem of meteor photography, indicating that the types of lenses at present in use are not economical for the purpose, and that large field angle and high speed are the important qualities (H.B. 852).

19. Many of the photographed meteor trails showed periodic changes of brightness, and two of them have been studied in detail (H. Repr. 40). The observed changes, including the splitting of one of the trails, are interpreted in terms of the dynamics of a spinning projectile in a resisting medium.

20. Dr. Fisher has made a study of the material of the meteor catalogue of von Niessl and Hoffmeister, and shows that the proportion of hyperbolic velocities of fireballs must be excessive (H.C. 331). He has rediscussed the famous meteoric procession of February 9, 1913, and finds that all the observations can for the first time be interpreted satisfactorily by taking into account the diurnal rotation and equatorial bulge of the earth (H. Repr. 47).

21. As a result of a campaign for the reporting of fireball observations to the Observatory it has been possible to discuss the showers of fireballs that took place on August 10 and October 16, 1927. Both seemed to constitute sparse showers, which are discussed in Harvard Reprint 50. Accurate observations of a fireball on August 13, 1927, permitted the determination of the height of disappearance (H.B. 853).

22. The study of the irregularities of apparition of meteor showers, with which Dr. Fisher is concerned, involves the reduction of observations to a standard epoch. He finds (H. Repr. 42) that the uncertainty of an approximate formula given by H. A. Newton affects appreciably the results of a previous investigation (H. Repr. 35).

23. Three Leonid meteors, photographed on the same plate in 1898, have been discussed in Harvard Bulletin 857 by Mr. Hogg. No admissible combination of corrections would reduce the radiant to a point, and we appear to have for the first time definite proof of a spread radiant.

D. *Stellar Systems*

24. A re-examination of the distribution and distances of stars and nebulae at the galactic center has been made by Dr. Shapley,

with results that essentially verify earlier studies. The galactic longitude and latitude of the center are 327° and 0°, respectively, and the distance from the Sun, as derived from the system of globular clusters, is of the order of fifty thousand light years.

25. In order to explore more thoroughly the region of the galactic center, a concentration of the variable star work has been directed to fields in Scorpio, Ophiuchus, Sagittarius, and neighboring constellations. A preliminary discussion of the hundreds of new variable stars that have been found in these regions indicates a high concentration of luminous stars at about the same distance as that indicated by the globular clusters for the galactic center.

26. In the course of the study of the galactic center, the distribution throughout sixty degrees of longitude and forty degrees of latitude has been examined for novae, planetary nebulae, dark nebulosity, open clusters, Class B stars, and variables of the Cepheid and long period types. Obscuring nebulosity is found to cover a considerable portion of the regions around the center.

27. The distribution of extra-galactic nebulae in the region of the galactic center is of high importance, in that it shows that some of the star clouds are free of obscuring matter transmitting the light of the stellar systems that lie far beyond the galactic boundaries.

28. Positions have been measured on Bruce photographs for several thousand of the new nebulae reported last year, and many new faint nebulae have also been found.

29. Fifteen new clouds of extra-galactic nebulae have been recorded on Bruce plates and are being studied with regard to classification, population, and distance.

30. Dr. Shapley and Miss Ames have practically completed the investigation of the Coma-Virgo cloud of nebulae. The system apparently lies at a distance of more than ten million light years, is two million light years in diameter, and is composed of nearly three hundred individual systems. The dispersion in apparent magnitude in the cluster is nearly three magnitudes, but its lower limit is difficult to disentangle from the general field of faint nebulae and the other three or four remote clouds of nebulae in Coma-Virgo.

31. The apparent diameters and ellipticities of ninety-five globular clusters are given by Dr. Shapley and Miss Sawyer in Harvard Bulletin 852. Apparent diameter and integrated photographic magnitude are correlated, especially for systems of similar concentration. These data are to form the basis of a revision of the distances of the clusters.

32. A number of unpublished investigations have been made on galactic and globular clusters, dealing mainly with star counts, variable stars, distances, and distribution. A catalogue of the magnitudes and colors of several hundred stars in Messier 22 is completed. A survey of all the open galactic clusters has been made on a uniform basis, using Harvard plates. Some new globular clusters have been added to the list, making the total 103. A special study of the variable stars in the open cluster Messier 4 is in progress. A monograph on star clusters is under preparation by Dr. Shapley and will probably be completed during the coming year.

E. *Spectroscopic Researches*

33. During the year, the fourth instalment of the Henry Draper Extension was issued. It contains the spectra of 4200 stars of the Helsingfors-Gotha catalogue of the Astronomische Gesellschaft, declination $+55°$ to $+59°$, inclusive.

34. Classifications of 7350 spectra have been made by Miss Cannon for the Henry Draper Extension, completing this part of the work in a region of eight hundred square degrees centered at 6^h, $+18°$. The central line of the Milky Way and a portion of the Taurus obscuring cloud are included in the region.

35. Observations of the spectra in a large region of the sky in Sagittarius and Scorpio are now in progress, to supplement the work on variable stars in the analysis of the galactic center. It is hoped that these spectra will be contained in the next section of the Henry Draper Extension.

36. The laborious work of determining the magnitudes of the stars for the Henry Draper Extension has progressed steadily under the direction of Miss Walton; altogether 42,779 estimates of photographic magnitude have been made.

37. Dr. Vyssotsky has photographed and classified a large number of spectra of faint stars, in continuation of the cooperative work of Harvard and the University of Virginia on the motions of faint stars. The observations are made with the 24-inch reflector and large objective prism, and classifications are based on Miss Cannon's standards.

38. The spectrophotometric work of the past three years has been continued; a summary of results and procedure is given by Miss Payne and Mr. Hogg in Harvard Reprint 43. Laboratory standardization, and the calibration of unstandardized plates, have been investigated and reported respectively by Dr. Dunham (H.B. 853) and by Mr. Hogg (H.B. 856).

39. A short study of line intensities for the important supergiant ϵ Aurigae, and a discussion of the quantitative composition of stellar atmospheres on the basis of photometric line intensities, was made by Miss Payne (H.B. 855).

40. The measurement of line width and contour has emerged into importance during the year, and much of the spectroscopic program has been devoted to this problem. Measures for the lines of hydrogen were published by Dr. Dunham (H.B. 858), and for those of calcium by Miss Payne (H.B. 858), and Mr. Hogg (H.B. 859). The use of the measures of line contour in analyzing the atmospheres of the stars quantitatively was discussed by Miss Payne (H. Repr. 48), and the results of the analysis were used by Miss Payne and Mr. Hogg (H.C. 334) to discuss the pressures in stellar atmospheres on the basis of the Saha ionization formula. The derived pressures are very low, and appear to be related to the gravity at the surfaces of the stars concerned.

41. The photometry of the continuous background of the spectra of some stars has also received attention. Professor Gerasimovič finds that the disappearance of the bright lines from the spectrum of μ Centauri was accompanied by a sensible decrease in the brightness of the star. For another B star with bright lines, P Cygni, he has derived the exceedingly low temperature of 7600° (H.B. 857), and he has also observed striking changes in the bright lines of the spectrum of this star (H.B. 852). He calls attention to seven additional B stars whose spectra show the bright lines of ionized iron (H.B. 851). Another study relating to background photometry was made by Miss Payne in the measurement of the depression of the apparent continuous background of the spectra of some A stars by the wings of the Balmer lines (H. Repr. 46). The absorption band at λ4200, attributed to cyanogen in second type stars, also occurs in early type spectra; but it now appears that glass absorption is principally responsible, and the need of a quantitative investigation of prisms and lenses in all equipment used in spectrophotometry is indicated.

42. A synopsis of the published material from all known sources on the spectra of comets, and a discussion of the spectral variation as a function of distance from the sun, has been made by Mr. Hogg (H. Repr. 57).

43. Precise spectrophotometric studies of eight nebulae, from plates made at the Dominion Astrophysical Observatory, Victoria, have been carried on by Professor Plaskett (H.C. 335). The dis-

cussion bears on the attribution of the lines in the nebular spectrum, the conditions in the nebulae, and the classification of the spectra of nebulae.

44. A tentative discussion of possible systems of classifying and relating the spectra of the nebulae and the O stars was put forward by Miss Payne in Harvard Bulletin 855.

45. An extensive investigation of the intensity of the lines of calcium in the spectra of Class B on Harvard plates was summarized by Dr. Otto Struve in Harvard Bulletin 857. On the basis of estimates on the spectra of seventeen hundred stars he extended and amplified his conclusions derived from the study of the brighter stars at the Yerkes Observatory; the intensities can be used in the estimation of stellar distances and of the absolute magnitudes of stars of Class B.

46. Spectra and color indices of stars at the north galactic pole are under study by Dr. Shapley and Miss Walton, who find evidence of abnormal blueness for dwarf stars of the second type.

F. *Miscellaneous*

47. Photographic measures of the positions of double stars have been in progress for many years under the direction of Professor King, and they are now published in Harvard Circular 332. The method is described, and results are presented for 435 double stars. Dr. Luyten has published the proper motions of sixteen pairs of double stars with common motion, discovered with the blink microscope.

48. The photovisual magnitudes and color indices of bright southern stars, and a revision of the magnitudes of the northern standards, are published by Professor King in Harvard Annals, **85**, No. 10. The magnitudes are measured by extrafocal methods. The relation between spectral class and color index for giant stars is one of the important results of the discussion.

49. Ionization by electronic impact in stellar atmospheres is discussed in Harvard Bulletin 857 by Professor Gerasimovič. He concludes that the quantitative effect of the electron impacts is negligible, but that the effect must occur to some extent, with important consequences for the distribution of atoms among their possible states, and consequently for the appearance of the corresponding spectral lines.

50. During the year the Observatory has published seventeen Circulars, ten Bulletins, containing eighty-seven notes and articles,

and three sections of the Annals. Ten papers have been printed in scientific periodicals and included in the Observatory series of reprints. Under the direction of Professor King, about 4650 plates have been taken at Cambridge with various instruments. At Bloemfontein two photographic telescopes are operated regularly during the period of construction of the permanent station.

HARLOW SHAPLEY, *Director.*

STEWARD OBSERVATORY
TUCSON, ARIZONA

EIGHTY-FOURTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1929

BY

HARLOW SHAPLEY

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1930

THE OBSERVATORY

To the President of the University:

Sir, — The Observatory's photographic collection continues to attract scientific visitors and to incite many requests from American and European observatories for observational data. There are now more than thirty members of the Observatory staff who work with the photographic plates, and it is largely the output of these workers on many problems that gives the Observatory its standing in the scientific world. Some of the most important contributions of recent years, however, have been the work of visitors to the Observatory — scientists who in one capacity or another have associated themselves with our scientific program.

Among the scientific visitors of the past year we should mention the following: Dr. Paul ten Bruggencate of Greifswald, Germany, formerly of Göttingen and of Lembang, Java, working on star clusters and variable stars, who plans to return to the Harvard Observatory next year to continue his studies of Cepheid variables; Professor Boris P. Gerasimovič of Kharkov, Russia, whose very profitable visit of nearly three years to the Harvard Observatory ended in June of this year, after he had completed here many researches in photometry and spectroscopy; Dr. Leon Hufnagel of Poland, who is working on spectra, variable stars, and statistical problems; Professor E. A. Milne of Oxford, who came to the Observatory to confer on problems of theoretical astrophysics; Professor Svein Rosseland of Norway, who is at Harvard University for a year as lecturer in cosmic physics and in general astronomy, and will carry forward researches in theoretical astrophysics; Dr. Albrecht Unsöld of Munich, who has investigated the distance of the Coal Sack nebulosities on Harvard plates and has taken part in conferences on the interpretation of line contours; and Dr. Alexander Vyssotsky of the University of Virginia, who again spent a number of weeks in spectroscopic work with the 24-inch reflector, and in the classification of the spectra of faint stars.

Dr. W. H. Steavenson, past president of the British Astronomical Association, and Professor E. W. Brown, President of the American Astronomical Society, both visited Harvard during the year in the special interests of the work on variable stars and star occultations carried out by various members and associates of the Observatory staff. Professor H. N. Russell of Princeton and Dr.

Theodore Dunham of Mount Wilson also came to the Observatory for scientific conferences.

Mr. Frank S. Hogg, holder of the Agassiz Research Fellowship during the past year, will continue his studies in Europe during the next; his successor in the Agassiz Fellowship, Mr. Bart J. Bok of Groningen, Holland, is undertaking researches in stellar spectroscopy; and a second Agassiz Fellowship is held by Mr. Eric M. Lindsay of Belfast, Ireland, whose investigations will also be in the field of astrophysics.

At the Boyden Station near Bloemfontein, South Africa, progress has been satisfactory. Half a dozen new buildings are now erected on Harvard Kopje; the temporary site at the Mazelspoort waterworks has been abandoned; and the Bruce refractor, with its new two-pier mounting, has again come into action. This telescope is being used for the study of extra-galactic nebulae; and in the rephotographing by Dr. Luyten of regions taken with the same lens some twenty years ago it is providing material for proper motion studies. The 60-inch reflector has been completed in the shops of Mr. Fecker at Pittsburgh, where (at the time of writing this report) it awaits final tests of mounting and of mirrors before being dismantled and shipped to South Africa.

Astronomical instruction in Harvard University has progressed in a very satisfactory way. Professor Plaskett has charge not only of the graduate work, but temporarily, with the help of Mr. Andrews, of the undergraduate instruction also. Professor Shapley, Professor King, Professor E. B. Wilson, Dr. Fisher, Miss Payne, and Mr. Campbell have also taken part in the instruction of graduate students. Professor H. T. Stetson, who has been in charge of the undergraduate instruction at Harvard for some years, has been called to the important post of director of the Perkins Observatory at Delaware, Ohio, where he will have charge of the largest telescope in the East — a 69-inch modern reflector. Professor Stetson was on leave of absence from Harvard during the second semester as exchange professor to Western colleges. He observed successfully the total eclipse of the Sun at a station in Kedah, on the Malay Peninsula, on May 9.

The progress in many researches during the past year is indicated by the summarized statements that follow.

A. Stellar Systems

1. Progress with the variable star program continues to contribute directly, as expected, to the interpretation of the structure

of the galactic system. Dr. Shapley and Miss Swope, discussing the new cluster type variables in Scorpio and Ophiuchus, present evidence that the center of the galactic system is occupied by a massive nucleus. Its galactic position (coinciding with that previously determined from globular clusters and from galactic rotation) is approximately 325°,0°; its distance is 14,400 parsecs, and its radius about 3800 parsecs (H. Repr. 52). The same distance accords with the new determinations of the luminosities of long period variables, of which many have been found in the direction of the galactic center (H. Repr. 53), and which now assume a new importance in the measurement of the distances of stellar systems.

2. Although there are well-defined patches of nearby dark nebulosity projected on the sky in the direction of the galactic center (as elsewhere in the Milky Way), Dr. Shapley shows that in the regions free of obvious dark clouds the system is effectively transparent, not only to the far edge of the galactic system, but also to the external galaxies at distances of the order of a million light years (H. Repr. 58).

3. In the course of the preparation of a Monograph on Star Clusters, Dr. Shapley has redetermined the basic quantities involved in the measurement of the system of globular clusters. The magnitudes of the variable stars, and of the bright stars used in the distance determinations, are summarized and used to obtain revised distances for 93 globular clusters; the data are given by Dr. Shapley and Miss Sawyer in Harvard Bulletin 867.

4. A rediscussion of the diameter-parallax curve on the basis of revised measures, made by Dr. Shapley in Harvard Bulletin 864, shows no positive evidence of space absorption of light within the region covered — a result not unexpected when compared with that of Section 5, which relates to the far more distant external galaxies.

5. The completion of the survey of the Coma-Virgo system of nebulae by Dr. Shapley and Miss Ames has been followed by a series of discusssions of the data. From the relation of angular diameter to apparent magnitude they conclude that space is effectively transparent in the direction of the cloud for at least a hundred million light years (H. B. 864). The distribution of the nebulae in position and magnitude yields, on analysis, evidence of five or six supersystems of various sizes and at different distances. Incidentally, the space-distribution of the nebulae in the direction named is found to be far from uniform (H. B. 865).

6. In the course of nebular work definitions are framed of *form*, *concentration*, and *surface brightness* (H. B. 866, 869). On analysis these lead to the conclusion that the concentration grades have an actual physical meaning, and that the most luminous galaxies tend to be the most nucleated (H. B. 868). The complex interrelations of form and concentration are summarized in Harvard Bulletin 866. Surface brightness has a rather small dispersion; the surface magnitudes tend to be brighter for the giant galaxies of the more distant groups — a further indication of space transparency (H. B. 869).

7. Dr. Shapley summarizes the data on measured radial velocity and integrated photographic magnitude for external galaxies and discusses the nature of the correlation between them, which is not necessarily linear (H. Repr. 61).

B. Spectroscopic Researches

8. During the year 21,005 classifications of spectra have been made by Miss Cannon for the Henry Draper Extension, mainly in the Scorpio-Sagittarius region, where the Harvard variable star investigations are concentrated. In addition, the spectra of various Cepheid variables have been classified; also (at the request of the Astronomer Royal) the spectra of about 360 stars to be included in a forthcoming Greenwich General Catalogue, and spectra of 325 comparison stars for use at the opposition of Eros in 1930–31, taken from Kopff's list (A. N. 5375, 5403).

9. The fifth instalment of the Henry Draper Extension is now being prepared for the press; spectra and magnitudes have been determined for 25,000 stars in the region centered at 6^h, $+ 18°$, comprising nearly nine hundred square degrees of the central portions of the Milky Way in Taurus, Auriga, Gemini, and Monoceros. It is believed that the catalogue is complete to $11^m.5$.

10. For the determination of magnitudes for the Henry Draper Extension, 57,190 estimates have been made under the direction of Miss Walton — 30,957 of them by Mrs. Olga Gerasimovič.

11. The spectra of forty-five globular clusters have been classified by Miss Cannon, who finds the integrated spectrum usually of Class F or G (H. B. 868).

12. Miss Cannon describes in Harvard Bulletin 862 the work on 8400 stars classified in the Gesellschaft zone from $+ 50°$ to $+ 59°$, giving data which show, among other things, the relative galactic concentrations and the spectral compositions at various hours of right ascension (and therefore various angular distances from the Galaxy). The preponderance of A stars is remarkable.

13. The important subject of the measurement of line intensity and contour has received considerable attention. A summary of the observed contours of the lines of hydrogen and ionized calcium throughout the spectral sequence was made by Miss Payne and Miss Williams (H. Repr. 55); maxima were derived from contour measures, and found to coincide with the maxima derived from depth measures and from crude estimates.

14. All the observed maxima of lines with known series relations were rediscussed by Miss Payne in the light of the new spectrophotometry; the redetermined maxima were then used to evaluate the constants of Milne's new generalization of the Saha formula. The observations are critical for the theory, but do not entirely substantiate it; the subject is under further investigation (H. B. 867).

15. A detailed spectrophotometric study of all normal northern stars of Class A brighter than the fourth magnitude, and all peculiar northern stars brighter than the fifth, has been made by Miss Williams; measures of the contours of hydrogen lines, depths of other lines, and photometry of the continuous background are included. The principal conclusions are: the total absorption of the K line is a good index of temperature for stars of Group A; the temperature range of the Draper Classes in Group A is very small; the contour of the hydrogen lines within a given class is related to luminosity — bright stars showing little Stark effect, fainter stars more; color temperatures are subject to a sensible seasonal effect (stars appearing redder in summer than in winter). Deviations from black-body distribution of energy are detected for some A stars of apparently low effective (color) temperature (H. C. 348; summary in H. Repr. 62).

16. In the preparation of her monograph on the spectroscopic study of high-luminosity stars Miss Payne has measured the contours and depths of a number of lines in normal and supergiant stars throughout the spectral sequence, calibrated the intensities in terms of theories of line contour, and deduced the changes in numbers of atoms from the spectral differences between Draper classes. These measures lead to a further test of Milne's generalization of the Saha formula, and to a physical analysis of the conditions of the atmospheres concerned.

17. The spectral changes of Cepheid variables have been quantitatively studied in the course of this work; some of the changes, such as the relative behavior of the lines of hydrogen and the metals, are readily explained; others, such as the changes of line

form with phase, are unexplained. From the spectroscopic criteria long period Cepheids are supergiant stars, with spectra showing the c-character; the luminosity is less for stars with lesser periods, and the cluster type variables are not c-stars.

18. Spectroscopic studies of Class M by Dr. Hogg relate to the intensities of the lines of neutral and ionized calcium. He has calibrated a method of deriving numbers of atoms empirically from measures made on spectra of very small dispersion, and deduced the degree of calcium ionization for a number of M stars. He also determined the relation of titanium oxide absorption in a number of classified bands to the decimal subdivisions of Class M, showing a general strengthening, and a progressive change of relative intensity, with advancing type.

19. The determination of star temperatures from photometry of the continuous background has been the subject of several researches: Professor Gerasimovič (H. C. 339) made an extensive series of measures for O and B stars, finding uniformly low temperatures for all the classes and a large dispersion in effective temperature within a given class, stars such as 55 Cygni having temperatures as low as 6000°. Such low temperatures he found to be statistically correlated with strong stationary calcium, and thus presumably with high luminosity (H. B. 864). He proposed to regard the high ionization in the spectra of such cool stars as a manifestation of "superexcitation."

20. Effective temperatures, from measures of the continuous background, were derived by Dr. Hufnagel for a selected list of giant and dwarf stars of Class K (H. C. 343); the mean temperatures of the dwarfs were found to be the higher, in confirmation of previous work. Professor Gerasimovič and Miss Payne similarly found the temperatures of dwarf F stars to be higher than those of supergiants of similar spectral class (H. B. 866).

21. Dr. Shapley points out that the cyanogen bands as criteria of absolute magnitude in Class K are not invalidated by the identification of the so-called cyanogen depressions in the spectra of early stars with instrumental absorption (H. B. 864; cf. H. B. 861).

22. Professor Gerasimovič emphasizes the changes in the spectrum of P. Cygni, and points out that they are not referable to instrumental or atmospheric causes (as had been suggested), but are associated with real stellar atmospheric changes (H. B. 867).

23. A method of calibrating otherwise unstandardized slit spectra with the aid of the intensities of multiplets in the comparison spectrum is described by Dr. Hogg (H. C. 337).

C. Variable Stars

24. Two hundred and forty seven new variable stars have been announced during the year, including two novae, one found by Miss Woods (H. B. 861), and one by Miss Swope (H. B. 870). The other new variables announced were found by Miss Cannon (H. B. 861), Miss Swope (H. B. 862), Waterfield (H. B. 863), and Miss Mohr (H. B. 866).

25. The program of work on Milky Way fields, described by Dr. Shapley in Harvard Reprint 51, has been carried on by several workers. In addition to the published lists, about a thousand unpublished new variable stars have been found.

26. The periods of fifty seven long period variables in the direction of the galactic center are given by Miss Swope in Harvard Bulletin 867. On the basis of these variables and the cluster type variables in the same region, Dr. Shapley evaluates the absolute visual magnitude of the long period variable at — 2.5 (H. Repr. 53). Professor Gerasimovič arrives at a similar value on statistical grounds (H. Repr. 54). These results give the long period variable great importance in the measurement of the distances of stellar systems. Elements for five long period variables are given by Miss Payne in Harvard Bulletin 868.

27. Several investigations of Cepheid variables have appeared during the year. Miss Swope has derived periods for thirty five cluster type variables in the direction of the galactic center (H. B. 863). Mr. Robinson discusses the variations of TU Cassiopeiae from 1900 to 1920, finding a regular period and a slightly variable light curve (H. B. 866). He has also determined period and light curve for XX Centauri (H. B. 869). Miss Swope discusses the star H. V. 4585 — a variable with the unusual period of about seventy days, which also shows a jump in epoch (H. B. 868). The star S Vulpeculae has been studied from Harvard plates and published visual observations by Dr. Hufnagel, who considers it a long period Cepheid despite anomalies in radial velocity and irregularities in period (H. B. 866). Mr. Waterfield, however, on the basis of Schönfeld's unpublished observations, regards the star rather as of RV Tauri type (H. B. 870).

28. Professor Gerasimovič has completed his study of semiregular variables. He discusses the changes in the period of R Scuti during 130 years (H. C. 333; H. B. 865). He has also investigated the variations of R Sagittae jointly with Dr. Hufnagel (H. C. 340), and gives (H. C. 341) a general summary of observation for RV

Tauri variables, and a tentative interpretation in terms of the rotation of an irregular star.

29. In a study of "variables of the intermediate group" (H. C. 342) Professor Gerasimovič classifies the variables not belonging to the "principal sequence" (which comprises Cepheids, RV Tauri stars, and long period variables). Periodic variables with fairly regular periods of less than a hundred days and small ranges are V Ursae Minoris (H. C. 338), TT Persei, and SS Cephei (H. B. 869). Stars with μ Cephei affiliations — long periods with superimposed irregular variations — are UZ Persei (H. B. 864) and TW Pegasi (H. B. 867), both of unusually long period (about 900 days), and possibly also SS Cephei. Cyclical variables are divided into regularly cyclic variables, including SV Ursae Majoris (H. B. 869) and SW Persei (H. C. 338), and erratically cyclic variables, such as UU Herculis (H. B. 857), Z Cancri (H. B. 862), TZ Aquilae, and UX Aurigae (H. B. 869). AI Scorpii is another semiregular variable, with a mean period of about 38 days, that shows no RV Tauri affiliations (H. B. 864). The variables of the intermediate group are to be considered physically unconnected with stars of the principal sequence, and mean density is shown not to be the governing factor in their variations.

30. Several other observations of variables have also been published. Professor Gerasimovič finds that SX Herculis, besides its fairly regular variation with a period of about 103 days, shows a long period inequality of about three thousand days; it is a true long period variable — the earliest known in spectral class (H. B. 869). The variations of the R Coronae star S Apodis, and of the two irregular variables V Pyxidis and RY Orionis, are illustrated in Harvard Bulletin 868. Dr. Shapley and Miss Woods publish recent observations of the peculiar variable XX Ophiuchi in Harvard Bulletin 868. Professor Gerasimovič questions the true variability of UY Herculis (H. B. 869). Anomalous maxima of SS Aurigae are pointed out by Mr. Campbell (H. B. 864), who has also obtained a well determined correction to the period of U Cephei (H. B. 862).

31. Mr. Campbell gives the usual bi-monthly predictions for long period variable stars in six Harvard Bulletins, the annual prediction in Harvard Circular 336, and the annual summary in Harvard Circular 345. The year's observations of selected peculiar variables are published in Harvard Circular 344.

32. About forty thousand observations of variable stars have been contributed to the Observatory by more than a hundred ob-

servers distributed throughout a dozen countries. Two thirds of these observations were made by members of the A. A. V. S. O., and the rest by members of the French, New Zealand, and Danish variable star organizations.

33. Some sixteen thousand observations of the peculiar variable SS Cygni (1907–1927), kindly communicated by the Secretary of the Variable Star Section of the British Astronomical Association, are to be included in the discussion of all available observations of the star made at and communicated to the Harvard Observatory during the past 33 years.

D. Meteors and Fireballs

34. Progress has been made in the photography of meteors and the testing of lenses. The Quadrantids were successfully observed and photographed; the Perseids failed on account of heavy clouds. Various tests of lenses for meteor photography have resulted in the purchase of a quartz lens for experiments in ultra-violet, and of a Ross W A Xpress lens, which is now in use for patrol work.

35. Photographic radiants for the Leonids of 1898 November 14 and 1901 have been derived by Dr. Fisher and Miss Olmsted (H. B. 870); in neither case is the radiant admissibly a point. A large number of visual observations of Leonids were brought in by the circulation of questionnaires.

36. Miss Olmsted has assisted Dr. Fisher in preparing papers dealing with the Quadrantids in general, and the Quadrantids photographed at Harvard on January 3, 1929; also in the preparation of a catalogue of Harvard meteor photographs.

37. Dr. Fisher has prepared a paper on the total lunar eclipse of June 15, 1927, and also a review of the work on lunar eclipses by Father Selga. Attempts made to observe the lunar eclipse of November 27, 1928 were almost completely frustrated by clouds.

38. Map tracings of the Perseid, Orionid, and Leonid regions have been prepared for the use of the American Meteor Society. Dr. Fisher, with the assistance of Miss Court, has brought up to date and checked the necessary Ephemeris data connected with meteor photographs.

39. Dr. Luyten has made a study of the large meteorite lying at Grootfontein, South Africa (H. Repr. 60; H. B. 868).

E. Photometry

40. A method of eliminating the Eberhard effect in surface photometry is described in Harvard Bulletin 870 by Dr. Hogg.

It is applied to determine the energy distribution in the image of the cluster Messier 13, both in photographic and visual light.

41. In an investigation, by means of star counts, of the Coal Sack and the surrounding regions, Dr. Unsöld shows that the obscuration in that direction merely makes the light of the underlying stars fainter by about a magnitude; it is at a distance of about 150 parsecs (H. B. 870).

42. The program of determining the photographic magnitudes of the brighter stars by out-of-focus photometry has been placed on a working basis during the year, and measures are in active progress.

F. Theoretical and Miscellaneous

43. Professor Milne points out, on the basis of his generalization of the Saha formula, that absorption lines should show no absolute magnitude effects at temperatures above those required to bring them to maximum, if (as other observations indicate) the general coefficient of absorption varies as the electron pressure (H. B. 870). Miss Williams (H. C. 348) finds observational confirmation of the theory for the K line in A stars.

44. Professor Gerasimovič has studied the question of the stability of gaseous stars with reference to the energy of ionization. He shows that the ionization energy always increases stability, and may rescue both supergiant and giant stars from Jeans' conclusion that if gaseous they must be fatally unstable (H. Repr. 59).

45. Professor Gerasimovič and Dr. Otto Struve discuss the observations of stationary calcium lines made by the latter in their bearing on the gaseous substratum of the galaxy; they evaluate its extent and motion, and show that it shares the galactic rotation (H. Repr. 56).

46. Dr. Hufnagel has found from the radial velocities and newly determined absolute magnitudes (see Section 24) of long period variables of Class Me, using the usual coördinates of the center of the galactic system, normal values for the rotation constant A, in place of the anomalous results obtained by other workers with less satisfactory data (H. B. 863).

47. The systematic corrections to the Greenwich and Cape parallaxes are discussed in Harvard Bulletin 870 by Dr. Luyten.

48. The absolute magnitudes of the nuclei of planetary nebulae are found by Professor Gerasimovič concordantly from the galactic dip, galactic rotation, proper motions, and novae at the nebular stage, to be about + 4.9. That this luminosity is considerably

brighter than those given by direct measures of parallax is perhaps an effect of selection (H. B. 864).

49. Dr. Luyten discusses Kreiken's suggestion that spectroscopic binaries are dwarfs in nature, and finds reason for questioning that conclusion (H. B. 870).

50. Professor Bailey, in an analysis of the hourly estimates of cloudiness, finds that the cloudiness at the new Bloemfontein station is considerably less than at Arequipa during the corresponding months (H. B. 866).

51. The proper motions of fifty stars have been published in Harvard Bulletin 869 by Miss Guiler, of Smith College. Miss Boyd has measured the motions of eight new proper motion stars (H. B. 863).

G. Historical

52. The past year has seen the publication of *A Source Book of Astronomy*, edited by Dr. Shapley and Miss Howarth — the first of a series of volumes of extracts from classical and fundamental investigations, containing quotations from 1500 to 1900.

53. Professor Bailey has completed during the past year a history of the Harvard Observatory, which is shortly to appear as Harvard Monograph No. 3. It deals with the development of Astronomy in New England, and the rise of the Harvard Observatory, which has gone hand in hand with that development. The leading problems that have been studied at the Observatory are discussed, and brief biographical sketches of the chief investigators that have been associated with the Observatory are included.

54. During the year the Observatory has issued nine Bulletins, fifteen Circulars, twelve Reprints, and one number of the Annals. "The Universe of Stars" has gone through a new edition. Over nineteen hundred accessions to the library are recorded. Forty seven hundred and twenty eight plates have been taken during the year with various instruments at Cambridge, and fourteen hundred and eighty five at the Bloemfontein station.

HARLOW SHAPLEY, *Director.*

EIGHTY-FIFTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1930

BY

HARLOW SHAPLEY

STEWARD OBSERVATORY
TUCSON, ARIZONA

CAMBRIDGE, MASSACHUSETTS
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1931

THE OBSERVATORY

To the President of the University:

Sir, — A few years ago the staff of the Observatory outlined a plan for a series of books, monographic in nature, dealing with original researches in progress at Harvard. One of the outstanding features of the past year's work at the Observatory has been the completion of three volumes in the series of monographs. "Star Clusters," by Dr. Shapley, a volume of 275 pages, is a discussion and summary of the author's researches in a significant field of stellar astronomy; it includes a general survey of the work of others, particularly the pioneer researches of Professor Bailey of the Harvard Observatory on the variables in star clusters. The volume presents a new treatment of the problems of the transparency of space, the dimensions of the stellar system, the distance to the center of the Galaxy, and the origin of galactic systems.

"The Stars of High Luminosity" is the subject of a volume of three hundred pages by Dr. Cecilia H. Payne. She has treated the high luminosity stars of all spectral classes on the basis of spectrophotometric analyses, paying special attention to variable stars. The significance of the high luminosity star lies in its wide distribution throughout the stellar universe; it is the only type of stellar body we can hope to study in external galaxies.

Professor Solon I. Bailey, who has been a member of the staff of the Harvard Observatory for more than forty years, has completed his monograph, "The History and Work of the Harvard Observatory." From its origin more than eighty years ago the Observatory has played a leading part in American astronomy, and at the present time its extensive and varied equipment permits it to take part in nearly all types of modern astronomical research.

There have been no major changes in the staff during the past year, except that Dr. Svein Rosseland, of Oslo, spent the past academic year as research associate and lecturer in astrophysics at the Observatory, and Mr. Bart J. Bok, of Groningen, Holland, who has been Agassiz Research Fellow during the past year, has been appointed Robert W. Willson Teaching Fellow and will have charge of the lectures in the introductory course in astronomy in Harvard throughout the coming academic year. Dr. Ernst J. Öpik, of Tartu, Estonia, has been appointed lecturer in astrophysics for

one year; he will devote particular attention to the problems of meteors while at the Harvard Observatory. Two new assistants have been appointed at the Boyden Station, Mr. N. Ferreira and Mr. E. Steyn; they are engaged in the operation of the photographic telescopes at Bloemfontein.

Steady progress has been made in the construction of the Boyden Station on Harvard Kopje. Five telescopes are now in systematic use. The chief programs are the southern sky patrol, the survey of extragalactic nebulae, the duplication of old plates for proper motion studies, the systematic photography of star clusters, and, most extensive of all, the research on Milky Way variable stars.

The progress during the past year in some of the more important researches is indicated by the summarized statements that follow. More than sixty scientific papers have been published in the course of these studies by members of the staff.

A. Variable Stars

1. The study of special fields both in and outside the Milky Way has been carried on during the year by seven workers under the general guidance of Miss Swope. Over seventeen hundred new variable stars have been found in eleven fields. The periods of more than a hundred have been determined. The data are not yet complete enough for significant discussion, but they promise results of great importance. Two of the fields in high galactic latitude (MWF 215, at $2^h\ 55^m$, $-24°.0$, and MWF 217, at $1^h\ 25^m$, $-27°.5$) were found to be unexpectedly rich, containing respectively twenty-one and ten variable stars.

2. There has been a concentration during the past year on the general aspects of stellar variability through the intensive study of the colors, spectra, and periods of a large number of long period and Cepheid variables. One of the more fundamental phases of the general study of the variable star will be found in Dr. Shapley's definitive discussion of the period-luminosity curve (Harvard Monograph No. 2, Chapter X), and his evaluation of the zero point. From other aspects Miss Payne has discussed the physical properties of variable stars in Harvard Monograph No. 3, Chapter XIV.

3. The relation of long period variables to the principal variable star sequence, and their interpretation by the pulsation hypothesis (Mon. No. 2, Section 54) has thrown the study of long period variables into a definite channel, which has guided most of the Harvard work on these stars during the past year. The problem of the

changes in period is closely related to the problem of the source and control of the variability; it has been discussed by Miss Payne and Mr. Campbell, who find no evidence that unpunctuality in attaining maximum is cumulative. This result is in accordance with a pulsation hypothesis, while a cumulative delay in reaching maximum would be difficult to interpret in terms of pulsation.

4. The relation of the spectra of long period variables to their type of variation has been discussed by Miss Payne and Dr. ten Bruggencate (Mon. No. 3 and H.B. 876). They find that the occurrence of absorption bands in the spectra, and the enormous influence of small changes of temperature on the intensity of the absorption, can be made to account in general terms for (1) the difference between the bolometric ranges and the visual and photographic ranges of long period variables; (2) the changes of color for variable stars of Classes M and N; (3) the relation of spectral class to color for these variables; (4) the relation of the luminosities of M (and N) stars to their periods; and (5) the general small-range variability of late type stars.

5. The hypotheses advanced by Miss Payne and Dr. ten Bruggencate to interpret the observed changes of long period variables rest largely on the data on the colors of these stars obtained at Harvard during the year. Professor Gerasimovič and Dr. Shapley examined the colors of thirty eight long period variables at maximum, and of six M stars at minimum. They found that for stars of Class M and Class S, color and period are unrelated; long period variables of Class M are slightly bluer than normal M stars — an interesting fact in view of their lower temperatures; for M stars, color and spectral class are unrelated and moreover the stars are no redder at minimum than at maximum. Stars of Class N, on the other hand, are redder for long period and late type than for shorter period and early type. A study of RV Centauri (spectral class N), published by Mr. Campbell and Miss Hoffleit (H.B.875), shows that the star is more than two magnitudes redder at minimum than at maximum. Detailed comparisons of mean visual and photographic light curves for eight long period variables are published by Mr. Campbell and Miss Payne, and by Miss Cannon, in Harvard Bulletin 872. The fluctuations in color are small, and show no definite relation to the phase.

6. The Cepheid variables on the international program sponsored by the International Astronomical Union have been the subject of various studies. Miss Cannon and Miss Walton have published a list of all the available spectra of the stars in the list.

Photographic magnitude sequences for all the variables have been determined by Miss Payne and will shortly be published. Mean photographic light curves for the variables in the first seven of the ten fields have been derived by Mr. Robinson (H.B. 871, 876).

7. Studies of the relation of period to form of light curve for Cepheid variables have been made by Mr. Robinson. The mean light curves published in Harvard Bulletins 872 and 876 for stars with periods between seven and thirty days confirm the progression of light curve with period. The shape of the light curve, expressed as a function of the sharpness of its rise to maximum, bears a linear relation to the logarithm of the period (H.B. 872).

8. In Harvard Circular 351 Dr. ten Bruggencate has discussed very fully the light and velocity curves of Y Sagittarii. The photometric data were obtained at Lembang and Harvard, the spectrographic data at Lembang, Mount Wilson, and Mount Hamilton. The chief results of this important paper are: the establishment of a change in photographic mean brightness, and in photographic range, accompanied by a change in the color of the star; the establishment of a change in radial velocity curve concurrent with the changes in brightness and range; the demonstration of absolute constancy of period over the interval studied; and the discussion of the possible interpretations of these observations.

9. The absolute brightness of Cepheid variables, in so far as it can be deduced from their spectral qualities, is discussed by Dr. Shapley and Miss Payne in Harvard Bulletin 872. They conclude that the c-character is present in the spectra of all except the cluster type variables, and that therefore the spectroscopic material is not incompatible with the absolute magnitudes given by the revised period-luminosity curve.

10. The relation between the periods and mean densities of Cepheid variables has been considered by Miss Payne (H.B. 876), who shows that the observed scatter of the period-spectrum relation leads, as an inevitable consequence, to a scatter in the visual and photographic period-luminosity curves, unless Cepheid variability is governed otherwise than by pulsation.

11. Photographic observations of three variable stars are presented by Dr. Hufnagel in Harvard Bulletin 873. RW Eridani is represented with some irregularities by a uniform period, and no periodicity is traceable in the variations of RX and RW Virginis.

12. Eclipsing binaries are now under systematic observations on Harvard plates, the work being supported by a grant from the American Academy of Arts and Sciences. The orbit of S Equulei

has been computed by Mrs. Shapley (H.B. 874) and she has made a special analysis of the ellipticities and densities of a dozen eclipsing variables observed by Jordan.

B. Meteoric Astronomy

13. Dr. Fisher, with the assistance of Miss Olmsted, has completed the catalogue of Harvard meteor photographs. This important list, which will represent the Harvard collection up to March 30, 1930, is now being published in the Harvard Annals.

14. The results of a search by a research group of the Bond Club of newspapers for the years 1803–1804 for data on the Lyrid shower of 1803 are reported in a paper soon to be published by Dr. Fisher.

15. The study of photographed meteor trails has been carried on under Dr. Fisher's direction. A study of the visual and photographic magnitudes of a meteor is described in Harvard Bulletin 872 by Mr. Millman and Mr. Wheelwright. Dr. Fisher and Mr. Dimitroff publish in Harvard Bulletin 877 a discussion of a very long meteor trail (nearly 53°), which deviated only one or two minutes of arc from a great circle path. Especial attention has been paid to trails showing sinuosity, flicker, and duplicity.

16. The mean cycle of the Leonids has been computed by Dr. Fisher from the old data of Newton, the new data from observations since 1864, and the historical researches of Hirayama. The result differs only slightly from that obtained by H. A. Newton.

17. From the results of a study of meteoric dust, and of magnetic dust found on a tower, on a roof, and in the flues of heating furnaces, Dr. Fisher concludes that the burden of proof lies with those who advocate a cosmic origin for these magnetic residues.

C. Photometric Researches

18. The program of determining the photographic magnitudes of all stars brighter than $8^m.25$ has been pursued actively under the direction of Miss Payne, and magnitudes are completed for all stars north of $+75°$, as well as for many fields further south.

19. Miss Payne has determined thirty six photographic sequences in Cygnus down to the thirteenth magnitude by polar comparisons; these stars will form the basis of the magnitudes to be published for the stars of the Henry Draper Extension in the Cygnus region.

20. Photovisual sequences down to the eleventh magnitude have been determined under Miss Payne's direction from existing material

for all the Harvard Standard Regions south of and including those at +15°. These sequences will be used as the basis for an extensive program on color indices for southern stars.

21. Red magnitudes of a number of northern stars have been measured by Professor King and Miss Ingalls (H.A., **85**, No. 11). The relation of the red to the photovisual color system is discussed on the basis of these measures.

22. Miss Sawyer has given in Harvard Bulletin 875 a synopsis and discussion of the photographic magnitudes in the galactic cluster N.G.C. 2477. The colors of stars in the galactic cluster κ Crucis have been discussed by Miss Cannon (H.B. 873).

23. The absorption of light of different wave lengths in the optical trains of various Harvard instruments has now been determined by Professor King and Mr. Sayer with a view to photometric precision in spectrophotometric problems. The results will be summarized in Harvard Bulletin 879.

D. Spectroscopy

24. During the year Miss Cannon has classified fourteen thousand stars for the Henry Draper Extension. The identifications and measurement of positions and magnitudes have involved several assistants, working under the supervision of Miss Walton.

25. The spectrophotometric survey of the stellar sequence that forms a part of Harvard Monograph No. 3 is summarized by Miss Payne in Harvard Bulletin 874; the numbers of effective atoms in the atmospheres of stars of different spectral classes are summarized, for the strongest spectral lines, by means of diagrams. She has also discussed the origin of the Wolf-Rayet spectrum (H.B.874). All the known O stars have been classified: the absorption stars on the system already sanctioned by the International Astronomical Union, and the Wolf-Rayet stars on a new system reflecting their degree of excitation.

26. The extensive study of the A stars made by Miss Williams during 1928 and 1929 is reported in Harvard Circular 348, and, more briefly, in Harvard Reprint 62. The results, based on measures of line contour and background distribution, may be summarized as follows: the total energy absorption of the K line is a close correlate of the effective temperature — an observation readily interpreted theoretically; the Henry Draper classification is a close index of temperature from A0 to F0; the line contour is related within any one spectral class to the luminosity of the stars; and, incidentally, there is a considerable variation of color index with season.

27. The "seasonal effect" on color index has been further discussed, with more extensive material, by Mr. Greenstein (H.B. 876).

28. The relation of line form to spectral class and luminosity is further discussed by Miss Anger (H.C. 352). On the basis of the spectroscopic material afforded by the galactic clusters Messier 7 and the Pleiades Miss Anger concludes that all the hydrogen lines (B5 to A3) are of sensibly similar contour; that their total absorption is a function of luminosity, irrespective of spectral class; that the latter observation can be explained in terms of the Stark effect; and that the two clusters discussed differ in the form of the relation of line intensity to luminosity.

29. The spectrophotometric temperatures of a number of K stars have been determined by means of short dispersion spectra by Dr. Hufnagel (H.B. 874). He concludes that such data are adequate to separate giants and dwarfs of similar spectral class.

30. Spectroscopic investigation by Professor Plaskett has been continued during the past year on solar and nebular problems. The observational determination of the contours of the solar Mg b lines to an accuracy of better than three per cent has been completed, and the comparison of these observations with theoretical prediction will suffice to determine the mechanism of the production of these typical absorption lines and also to answer some important questions in atomic physics.

31. A preliminary study of means of photographing the spectrum of solar granulation, carried out at Victoria by Professor Plaskett during the past summer, has met with enough success to justify a full time investigation this coming summer.

32. In the nebular field Professor Plaskett has carried out a complete observational program on the continuous spectrum of the planetary nebulae. The plates so obtained, after analysis on the microphotometer, will suffice to determine the energy distribution in this continuous spectrum from the extreme violet (λ 3300) to the red of Hβ. The material, besides giving information on the origin of the mysterious continuous spectrum, will in the case of the Balmer continuous spectrum also be useful in determining the electron temperatures of the nebulae observed.

33. Using slit spectrograms taken at the Dominion Astrophysical Observatory, a spectrophotometric study of the behavior of the three hydrogen lines, Hβ, Hγ, Hδ, throughout the spectral sequence O6—Mb has been made by Mr. Lindsay under Professor Plaskett's direction. The theoretical relative intensities of the

lines in some iron multiplets have been used for the calibration of the microphotometric tracings. From the line contours obtained in this way the maxima of these lines could be studied in detail. An exponential formula has been found to fit the contours satisfactorily and by means of it total absorptions have been calculated.

E. Stellar Systems

34. The problems of the structure and origin of stellar systems are dealt with from many aspects in Harvard Monograph No. 2. Studies of the luminosity curves of supergiant stars in the Magellanic Clouds are in progress and the variable stars and clusters in these nearest of external galaxies are published in current researches. The basic hypothesis of the Supergalaxy is defined and discussed by Dr. Shapley in Harvard Circular 350. What is apparently a supergalaxy of similar type is described in Harvard Bulletin 874 as a remote cloud of galaxies in Centaurus.

35. The distances of the Coma-Virgo group of nebulae are estimated (Shapley and Miss Ames) in the sixth of a series of papers on these supersystems (H.B. 873). Distances ranging from ten million to more than 150 million light years are found. The relative numbers of spiral and elliptical galaxies are examined for various groups and found to differ conspicuously. An extension of the bright Coma-Virgo supergalaxy to the southeastward a distance of at least five million light years has been traced. In all these investigations the most important contributing agent is the Bruce telescope at the Boyden Station in South Africa.

36. Steady progress is being made in the general survey of the southern sky for faint nebulae. Hundreds of new objects have been found, and positions, classes, dimensions, and magnitudes have been obtained for several thousand. The general outline and structure of the Milky Way is emerging from these studies.

F. Miscellaneous

37. The results of a cooperative program, extending over Canada, Alaska, and many observatories in the United States, for the observation of the total lunar eclipse of 1927 June 15, are reported by Dr. Fisher in Harvard Reprint 66. The response of the widely scattered observers showed the results that can be expected from cooperative work.

38. Observations of the times of first and last contact, at the solar eclipse of April 28, 1930, have been made under the direction of Professor King.

39. In two discussions of the statistical properties of double stars (H. Repr. 63 and 64) Dr. Luyten evaluates a formula for the estimation of the period of a relatively fixed system and determines the mean period of double stars in space. The systematic and accidental errors of modern trigonometric parallaxes have also been discussed and evaluated by Dr. Luyten (H. Repr. 65; H.B. 873).

40. In a critical discussion of the determination of the galactic rotation from radial velocities, Mr. Bok concludes that the only center of rotation compatible with the facts is the one given by Oort; a rotation round an axis in Carina is inadmissable (H.B. 876).

41. During the year 5293 photographic plates have been made with the telescopes at Cambridge, and 3944 at Bloemfontein. There have been 2240 accessions to the library.

HARLOW SHAPLEY, *Director.*

STEWARD OBSERVATORY
TUCSON, ARIZ.

EIGHTY-SIXTTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1931

BY

HARLOW SHAPLEY

CAMBRIDGE, MASSACHUSETTS
PUBLISHED BY THE UNIVERSITY
1932

THE OBSERVATORY

To the President of the University:

Sir, — During the past ten years it has become increasingly difficult to make a satisfactory report of reasonable length concerning the progress of scientific work at the Observatory. In this interval the number of workers has trebled, and the fields covered by the investigations of the members of the staff have expanded and become more complicated. Each year between fifty and a hundred papers embodying the results of these investigations are published from the Observatory.

It now appears advisable to make no further attempt to give a general synopsis of the scientific results in the Annual Report. Information concerning research problems can be obtained from the technical publications of the Observatory; to the Annual Report is left the description of the growth and changes in plant and equipment, the initiation of the larger programs, changes in the staff, and the special needs of the Observatory.

The New Endowment

The first part of the program for obtaining funds for new development was completed this year with generous gifts to the Observatory, amounting to a million dollars, from the Rockefeller Foundation and from the Wyeth Bequest to Harvard University. This new "Harvard Observatory Fund," as planned by the Director with the assistance and advice of members of the Visiting Committee, will amount, when realized, to $1,800,000. Several important contributions were made by friends of the Observatory. One phase of the program, the founding of the Edward C. Pickering Memorial Fund, was aided by a contribution of several thousand dollars from the American Association of Variable Star Observers.

New Building for Library and Photographic Plates

For three decades the collection of astrophotographic negatives on glass has been the most valuable asset of the Harvard Observatory. It is therefore a great satisfaction to the astronomers of the world that this important collection is to be insured for the future through the provision of adequate fireproof quarters. Of the several

new developments at the Observatory undoubtedly the most important is the new building in which is a four-tier plate vault with a capacity of approximately one million photographic plates.

The new building is about thirty per cent larger than the present brick building, which it adjoins on the west. It contains fourteen offices, a small auditorium with a wide balcony which will hold the major part of the Observatory library, two dark rooms, and the plate vault which contains stacks adequate for additions to the collection during the next fifty years. On the upper three tiers of the plate vault, desk space is provided for more than twenty observers.

The new building, begun in July 1931, will be ready for the transfer of library and photographs in February or March 1932.

The Oak Ridge Station

The second most important item in the development of the Harvard Observatory is the establishment of an out-of-town observing station for the northern telescopes in order that the quality of the work can be more nearly comparable than now with that carried on at the Boyden Station at Bloemfontein, South Africa. Through the generous gift of nearly forty acres of land on the highest hill in northeastern Massachusetts, Mr. and Mrs. Alfred C. Fuller of Belmont have provided the Observatory with the much needed out-of-town site. The land is in the town of Harvard, two miles east of Harvard village and twenty-six miles northwest of Cambridge. In its isolation from highways, railroads, and highly illuminated towns and cities, the location is ideal. The Observatory buildings will be situated in the midst of thick woods of maple, oak, pine, and birch, and thus be protected throughout the year from wind, dust, and artificial light.

The patrol cameras, the 24-inch reflector, and the 15-inch photographic doublet will all be transferred during the coming year from the Cambridge headquarters on Observatory Hill to Oak Ridge. Within two years this equipment will be supplemented with a new 61-inch reflecting telescope. The design for the mounting of the new reflector is already made; the building to contain it will be modeled after that now under construction at Bloemfontein for the Observatory's southern 60-inch reflector. Temporarily the second 60-inch Common mirror, already in the possession of the Observatory, will be used in the new telescope, thus permitting further experimentation before ordering the permanent mirror.

A few members of the Observatory staff will probably move to

Oak Ridge; others who take part in the observational work will go out to the site only for the observing hours, retaining residence and office in Cambridge. Although the most important photographic equipment will be moved out of town, there will remain on Observatory Hill in Cambridge, at least for some years, four photographic and three visual telescopes. Some of these instruments are almost wholly for the use of graduate students in astronomy; others are involved in systematic research programs that do not require the isolation attained on Oak Ridge.

The Expedition to Arizona

The third item of the new development plan at the Observatory is the expedition to northern Arizona. The expedition is under the direction of Dr. Ernest J. Öpik of the Harvard Observatory and Professor Samuel L. Boothroyd of Cornell University, and will be maintained in the field for the study of the frequency, altitudes, and speeds of meteors for at least twelve months.

A preliminary report from Arizona indicates that the expedition will yield more important results than we anticipated. The meteors are more numerous than expected and the observing conditions more satisfactory. In addition to Öpik and Boothroyd, one Cornell observer and four on the Harvard staff are devoting their entire time to the meteor program.

The expedition to Arizona is supported in part by a grant from the Milton Fund. A grant from the Rumford Fund of the American Academy provides for some of the special equipment. A device for determining the speeds of meteors, designed by Dr. Öpik, was built in the Observatory shop; one of the huts for observers was built here and shipped to Arizona and three others have been constructed in Flagstaff, two of them at the expense of the Heckscher Fund of Cornell University. The staff of the Lowell Observatory has coöperated very generously in providing office quarters for the expedition and in many other ways.

The Pickering Memorial

Ten years ago a committee was formed for the raising of funds to endow the work of amateurs in astronomy, with especial reference to the American Association of Variable Star Observers, which has its headquarters at the Harvard Observatory. The completion of this fund to commemorate the active interest of the Association's founder, Professor Edward C. Pickering, is now marked by the establishment of a Memorial in the Harvard Observatory.

Mr. Leon Campbell, who has long been the Observatory's chief representative in the Variable Star Association, is the Pickering Memorial Astronomer. One large room at the Observatory has been set aside as the Pickering Memorial room; it will be the headquarters of the American Association of Variable Star Observers and will contain the Association's library, lantern slide collection, and scientific records.

The Boyden Station

Under the superintendency of Dr. J. S. Paraskevopoulos the Observatory's program on southern stars and nebulae has been carried forward energetically throughout the year. Five photographic telescopes are in continual use, with six observers employed. The progress with the construction of the 60-inch reflector has been satisfactory. A turret has been completed at the factory of Hubert Davies and Company in Johannesburg. The observing platform, of novel design, was completed last winter at the River Works of the General Electric Company in West Lynn, Massachusetts, and has now been delivered to Harvard Kopje, Bloemfontein. The trucks, truck wheels, turning gear, and accessories have been designed by Professor Gerrish and manufactured in Cambridge. The mounting of the telescope is under way and the foundations of the building are completed. The mounting is of the two-pier type and is partially below the surface of the ground in order to avoid troubles due to wind. It is hoped to have the telescope in operation by the summer of 1932.

A serious need that has developed at the Boyden Station is a residence for the unmarried assistants. At present they are unsatisfactorily housed at the foot of Harvard Kopje in shacks belonging to the Water and Light Department of the City of Bloemfontein. Through the always generous coöperation of the Municipality it would be possible to provide a satisfactory residence at the cost of approximately sixteen thousand dollars. The new funds of the Observatory cannot be diverted to the Boyden Station since they were specifically given for other purposes.

The Staff

Except for the changes noted below the staff of the Observatory has remained essentially as in the preceding year. In all there are more than sixty persons taking part in the scientific work, of which approximately ten are part-time workers and five are volunteer associates.

The Observatory has lost through death two of its most eminent members, both of whom had been associated with Harvard for more than forty years. On June 5 Professor Solon I. Bailey, Phillips Professor, Emeritus, died at his summer home in Norwell, Massachusetts, and on September 10 Professor Edward S. King, who had succeeded Bailey as Phillips Professor and had also become Emeritus on September first, died at his home in Cambridge. Professor Bailey had been instrumental in building and operating the southern station of the Observatory; Professor King for many years had been in charge of the photographic work. Professor Bailey's *History of the Harvard Observatory* appeared during the past year, and he had just completed his long series of studies of Peruvian meteorology. During the year Professor King had also published a volume, *A Manual of Celestial Photography*, and a few days before his death had completed a biography of Professor Bailey.

The courses in astronomy in the College have been organized as a department in the Division of Physical Sciences. The tutorial system was inaugurated during the year and B. J. Bok, L. B. Andrews, L. S. Barnes, and F. D. Miller have been appointed tutors. Mr. Barnes and Mr. E. M. Lindsay have been appointed laboratory assistants in Astronomy 1.

Dr. Fred L. Whipple has joined the staff and has charge of the systematic photographic work for the Cambridge and Oak Ridge stations; he is also assisting in the inauguration of construction work on Oak Ridge. Mr. Philip S. Riggs and Miss Emily M. Hughes have been appointed research assistants; Mr. Peter M. Millman and Mr. William A. Calder are Agassiz Research Fellows and Miss Augusta H. Morse and Miss Georgette Maulbetsch are Pickering Fellows; Mr. François R. de Villiers is a new observer at the Boyden Station. Miss Gladys Wickson has been appointed editor of the Observatory publications.

Dr. Ernst J. Öpik has been appointed lecturer and research associate in astrophysics for two years in order that he may continue his participation in the Observatory studies of meteors. Professor Robert H. Baker of the University of Illinois has been appointed research associate for one year; he is engaged in the study of faint extra-galactic nebulae on Harvard plates.

Dr. Kyrill Ogrodnikoff of Moscow and Dr. Eberhard Hopf of Berlin have carried out investigations in the Observatory during the past year under grants from the Rockefeller Foundation.

HARLOW SHAPLEY, *Director.*

EIGHTY-SEVENTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1932

BY

HARLOW SHAPLEY

STEWARD OBSERVATORY

CAMBRIDGE, MASSACHUSETTS
PUBLISHED BY THE UNIVERSITY
1933

THE OBSERVATORY

To the President of the University:

Sir, — The Observatory's research staff lost a valuable member in the accidental death on June 26 of Miss Adelaide Ames, who had been an assistant at the Observatory for seven years. In the field of external galaxies she had at the age of thirty one attained an international reputation which was recognized by appointment to the International Committee on Clusters and Nebulae. Miss Ames was an active participant in the administrative problems of the Observatory and at the time of her death was in general charge of arrangements for the entertainment of the International Astronomical Union at its Cambridge meeting.

Professor Harry H. Plaskett, Professor of Astrophysics, resigned at the end of the year to become Savilian Professor of Astronomy in Oxford University. Fortunately for the Observatory he continues informally as adviser in the construction of some of the new Observatory spectrographs as well as in the guidance of some of the researches that have been begun under his direction. Professor Plaskett's work with graduate students in astrophysics has been taken over, beginning September 1, 1932, by Dr. Donald H. Menzel, formerly of the Lick Observatory. Dr. Menzel, who was at the Harvard Observatory as a student in 1922–24, worked in the field of stellar spectrum analysis chiefly. He has since become a leading student in astrophysical problems of the solar system, with special emphasis on the solar chromosphere. Mr. Loring B. Andrews, instructor in the Department of Astronomy, has been appointed Executive Secretary of the Observatory.

Professor Boris P. Gerasimovič of Kharkov and Pulkovo, Russia, Professor E. Hertzsprung of Leiden, Holland, Abbé G. Lemaître of Louvain, Belgium, and Professor K. Lundmark of Lund, Sweden, have carried on special investigations at the Harvard Observatory for short intervals during the year. Father D. O'Connell of Sydney, Australia, has come to the Observatory for approximately two years for the study and investigation of the photographic light curves of peculiar variable stars.

The past year has been conspicuous in the history of the Harvard Observatory for material growth and for the success of scientific programs. Following the precedent of last year I report in the following paragraphs only on the growth and changes in plant and equipment; I mention here only as a matter of record that the Ob-

servatory was the host for the Fourth General Assembly of the International Astronomical Union which was held in Cambridge during the first week of September, and that all the Harvard Observatory eclipse parties at the total solar eclipse of August 31, especially the principal party at West Gray, Maine, were favored by excellent weather conditions and attained satisfactory scientific results.

Building D

The new astrophotographic building on the Observatory grounds in Cambridge was completed in March and the photographic plate collection was immediately transferred into the new fireproof plate vault. The most valuable part of the Observatory library was also transferred to the new building and all the offices are occupied. On March 23 the new building was appropriately dedicated in the presence of representatives of several of the eastern observatories and the dedication ceremony was made the occasion for conferences on Astrophotographic Problems and the Time Scale. Among those taking an active part in the ceremony were President Lowell, Professor Arthur Holmes of England, Professor Lane of Tufts College representing the Visiting Committee, and Professors Brown and Schlesinger of Yale.

Oak Ridge Station

Progress has been surprisingly rapid in the construction of the various buildings for the Observatory's out of town site at Oak Ridge. By October first two patrol cameras and the 16-inch and 24-inch telescopes had been transferred from Cambridge and were in active operation. The meteor platform was used successfully by Dr. Fisher for the Perseids in August and preparation has been made for extensive observation at Oak Ridge of the Leonids in November. Data now available indicate that a gain of approximately eight tenths of a magnitude has been secured by moving the photographic instruments out of Cambridge.

The Agassiz Cottage, given by Mr. George R. Agassiz for the recreational and vacational uses of the staff of the Observatory, has been completed and is in use. The Cottage can accommodate as many as twelve persons and will doubtless play an important part in the life of the Observatory staff and in the success of the operation of an out of town station.

The Central Building, with living quarters, motor generator room, and dark room, has been completed and the Seismographic Station, built at a cost of approximately ten thousand dollars for

the Geophysical Committee of Harvard University, is nearly finished; the Lodge and the building for a new 8-inch Ross lens, with accompanying darkrooms, will be constructed within the next few months.

Progress with the building and mounting of the 61-inch reflector has been rapid. The building itself, with rotating turret, is practically completed; the piers are installed and the mounting will probably be delivered by J. W. Fecker of Pittsburgh within six months. The twelve-sided turret is a duplicate in general design of the 60-inch turret at the Boyden Station, but the materials, the mounting, and the building are different. The cornerstone of the 61-inch building was laid by Sir Frank Dyson, the Astronomer Royal and President of the International Astronomical Union, on the occasion of a visit of three hundred and fifty members and guests of the Union to Oak Ridge on September 4. The Common mirror mentioned in last year's Report has been returned from the Perkins Observatory, where it was in temporary use; tests of its surface have been made by the knife-edge and Hartmann methods by Mr. Calder and Mr. Barnes. The mirror proves to be more satisfactory with respect to astigmatism and zonal errors than had been expected. It will no doubt prove to be an entirely satisfactory glass for spectroscopic and photo-electric investigations. The secondary mirrors will probably be made of Pyrex in anticipation of use with the final mirror for the 61-inch telescope which it is hoped can be made of some low expansion glass. For use with the 61-inch reflector and with the 60-inch reflector of the Boyden Station two large three-prism ultra-violet stellar spectrographs are under construction in the shop of David W. Mann in Cambridge.

The Estonian Computing Bureau and the Arizona Expedition

The reduction of the visual observations of meteors carried on in Arizona as described in the last Report is an important and laborious part of the general study of meteors recently inaugurated at the Observatory. Since Dr. Ernst J. Öpik, research associate of the Harvard Observatory, spends a part of each year at the University of Tartu it has proved advantageous to carry on the reductions with a staff of experienced workers at the Tartu Observatory. We find that the reductions, which are carried forward with the aid of a grant from the Milton Fund of Harvard University, can be completed at less than one third the cost that would be necessary if the work were done in Cambridge. In the absence of Dr. Öpik the

bureau is operated with seven members under the superintendence of Miss Alide Piiri.

After the return of Professor S. L. Boothroyd from Arizona to Cornell University the systematic observations of meteors at the stations near Flagstaff, Arizona, have been carried forward under the direction of Mr. Donald Hargrave. Except for the midwinter months of 1931–32, the weather has been satisfactory and the number and accuracy of meteor records indicate that we should be able to make the anticipated important contributions to knowledge in this branch of astronomy. The serious restriction in the Observatory's operating budget has made it difficult to continue the meteor work through a second year. Temporarily at least the observations can be continued, although the reduction, discussion, and publication of results may need to be considerably delayed.

The Arizona observers have for several months supplemented the visual work with a determined attempt to photograph the spectra of trails of shooting stars, using equipment supplied by Dr. P. M. Millman, who will continue at the Harvard Observatory his investigations on the meteor spectra. At Arizona three new spectra have been photographed this year to add to the nine already known before from all sources.

The Boyden Station

In September the 60-inch mirror reached South Africa and now should be rapidly installed. During the past year the mounting and the observing tower have been erected by Dr. Paraskevopoulos and his assistants. The turret has been erected, covered with redwood shipped from San Francisco, and has been found to operate easily and successfully. Except for minor alterations and repairs to the several photographic telescopes, including the readjustment of the lenses for the 24-inch refractor, there have been no other new developments at the Boyden Station.

We have not yet been able to meet the needs for residence for the scientific assistants. The four men are very unsatisfactorily housed, and with the increased staff necessitated by the completion of the 60-inch reflector the inconvenience of decent accommodations will be even more seriously felt. Under better general economic conditions the city of Bloemfontein would probably have been able to build the residence for us in anticipation of a later purchase; but that is no longer possible, and the large decrease in the Observatory's income for operation has exhausted rapidly the reserves of the Boyden Station.

Miscellaneous

One part of the Oak Ridge development is the rearrangement and remounting of some of the photographic telescopes. Four of the smaller instrument buildings in Cambridge have been removed from the grounds and one new one has been constructed for the 12-inch Metcalf refractor. The 12-inch telescope has been too little used in past years because of its deficient mounting. We have now had constructed a new mounting by J. W. Fecker, of the two pier type, and within a month the instrument will again be in use in special photometric and patrolling problems. Two new mountings for 8-inch telescopes are also under construction, one of which will be installed in Cambridge to replace the very old and constantly used mounting for the 8-inch Draper telescope. The second 8-inch mounting either will be sent to South Africa to replace the old Bache mounting or will go to Oak Ridge to accommodate a new 8-inch Ross lens.

Publications of the Observatory during the past year have covered many fields and represent the work of more than twenty investigators; but they have been much less extensive than in past years because of budgetary restrictions and during the coming year must be still further reduced. Fortunately many of the papers emanating from the Observatory can be published in current journals and issued as Harvard Reprints; but the extensive and important catalogues of stellar spectra, of stellar magnitudes, and of the external galaxies must be published in the Observatory Annals, and an increase in Observatory funds especially for publication purposes is an urgent need.

Members of the Observatory staff and members of the Visiting Committee have formed an unemployment fund which will enable the Observatory to give clerical work of a routine character to needy persons of Cambridge.

It has been the Observatory's good fortune to have assigned to it the services of ten student assistants from the Harvard Houses during the present academic year. These men fit admirably into the Observatory's organization, and for those students specializing in scientific subjects the work should be important both as instruction and as experience in scientific research. They work with photographic plates on stellar and nebular distribution, in the computation of special tables, in the measurement and reduction of photometric plates, in the library, and with the card catalogues for the photographic collection.

HARLOW SHAPLEY, *Director.*

EIGHTY-EIGHTH

ANNUAL REPORT

OF THE

DIRECTOR

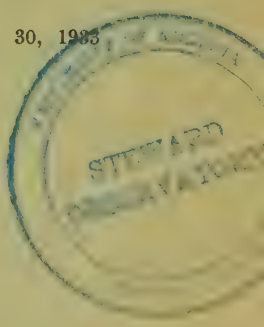
OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1933



BY

HARLOW SHAPLEY

CAMBRIDGE, MASSACHUSETTS
PUBLISHED BY THE UNIVERSITY
1934

THE OBSERVATORY

To the President of the University:

Sir, — At the end of a year that has been unusually successful in the progress of scientific investigations at the Observatory, I report not on the nature of these problems but, because of space limitations, only on the changes in personnel and on the growth and alterations in plant and equipment.

In the death of Mr. W. F. H. Waterfield at Bloemfontein on May 15 as the result of a motorcycle accident the Observatory suffers the loss of a valuable member of the scientific staff. During his five years as chief assistant at the Boyden Station Mr. Waterfield had become an expert observer with the Bruce 24-inch refractor, and much credit goes to him for the continued success of the survey of faint galaxies and for the progress of the work on proper motions of faint stars. His son, Hugh Waterfield, appointed assistant during the year, resigned in July to return to England. Mr. Ferreira, on leave of absence from the Boyden Station for several months because of illness, returned to Harvard Kopje in August. Mr. Reginald Skea has been appointed assistant during the year.

The financial situation made it necessary to close the work of the Arizona Meteor Expedition on August first after its successful operation for nearly two years. Grants from the Milton Fund and from the Rumford Fund of the American Academy of Arts and Sciences have helped in the prosecution of this first prolonged scientific effort to obtain systematic data on the heights and speeds of shooting stars. The four members of the observing staff at Flagstaff, Arizona, did very creditable work on this difficult problem. If work of the same sort is renewed in the future their experience and faithfulness should be remembered.

The computing bureau for the reduction of the abundant Arizona material on meteors has been continued at Tartu, Estonia, under the immediate direction of Dr. Öpik and his first assistant, Miss Alice Piiri. The work will be essentially completed and the bureau disbanded about the first of January, 1934. We regret the loss to the bureau through the sudden death in September of Miss Aphrodite Rosenberg, who had served for many months as one of the special computers. Dr. Ernst J. Öpik, whose work for the past two

years has been chiefly in the field of meteors, completed his term of appointment as research associate on September first; he has fortunately been able to accept reappointment for the second semester of the coming year, and upon his return to Harvard will continue his studies of the accumulated meteor observations. He will also continue his researches on problems in stellar astronomy, including the conducting of a seminar in cosmic physics in coöperation with advanced students at the Observatory.

Professor E. W. Brown of Yale University gave a series of seminars on modern problems of celestial mechanics during the past winter and advised the members of the staff on current research problems. Rev. D. J. K. O'Connell, S.J., after two years at the Observatory, has gone to his new post at Sydney, Australia; his work at Harvard was confined largely to investigations of irregular variable stars. Dr. Peter M. Millman and Dr. Carol A. Rieke spent the year at the Observatory as special research fellows, the former under a grant from the Royal Society of Canada and the latter as a fellow of the American Association of University Women. Dr. Millman continued his researches on the spectra of meteors with much success, and Dr. Rieke extended her important investigation of absolute magnitudes of stars and the distances of galactic star clusters.

Dr. William A. Calder has joined the staff of the Observatory and is resident at Oak Ridge, where he is continuing his work on the photo-electric photometry of the stars, the Sun, and the Moon. Mr. Zach Gibbs has been appointed general assistant at the Oak Ridge Station, to help with the routine observing programs. He devotes part of his time to technical assistance at the seismographic station established on Oak Ridge by the Committee on Geophysics of Harvard University.

Dr. Theodore E. Sterne joined the staff for the current academic year as research associate; he is devoting his attention chiefly to theoretical problems of Cepheid variation, the changes in the periods of variable stars, and the magnetic field of the Sun. Dr. Samuel L. Thorndike is working as a volunteer associate in the field of spectrophotometry.

In Cambridge

The most important addition to the astrophotographic equipment at the Cambridge headquarters of the Observatory is the 12-inch photographic doublet. The lens, made by Metcalf, has for several years been in the possession of the Observatory. A new

mounting, made by J. W. Fecker of Pittsburgh, has now been installed in a new building erected especially for the purpose. The mounting is of the two pier type, with the usual electric drive of the Gerrish design. The telescope is employed in red magnitude programs, for which its present location is very suitable, and also in a systematic patrol of the ecliptic. The other astrophotographic equipment now in operation in Cambridge includes the 8-inch Draper telescope, assigned to problems in photometry, star distribution, variable stars, yellow magnitude sequences; and the "AC" camera, used in the systematic sky patrol and in stellar distribution work in coöperation with the Astronomical Institute at Amsterdam. The 11-inch Draper telescope has been used a part of the time in problems of stellar spectrophotometry, but the mounting must be overhauled and the dome recovered before this instrument can be used efficiently.

Three visual telescopes, the 15-inch, the polar 12-inch, and the Post 6-inch, are in occasional use in Cambridge; it is proposed to make the 15-inch telescope more effective by the installation of a motor drive.

In the shop of David Mann two new 3-prism ultraviolet spectrographs have been brought nearly to completion during the year, in preparation for spectroscopic work with the reflectors at Oak Ridge and at Bloemfontein. The Alvan Clark and Sons Company has made of pyrex glass a Newtonian flat for the 61-inch reflector. The preliminary tests show the workmanship to be very satisfactory.

Under the supervision of Professor Gerrish much work has been done in the Observatory and affiliated shops for the Oak Ridge Station. Five new patrol camera mountings are practically completed, four of them to be used at Oak Ridge and one sent to the Boyden Station. These mountings are of new design in some important respects and they should add greatly to the quality of the patrol plates, which form an important part of the Observatory's astrophotographic collection. Many plateholders, control manuals, and other accessories for the Oak Ridge telescopes have also been made in the Observatory shop.

Measuring machines for the photographic plates are a serious concern for the near future; good instruments are expensive and the old equipment of the Observatory has never been sufficient. Two of our best measuring engines are borrowed from neighboring colleges. When the new spectroscopes are in action some special provision must be made outside the regular operating budget to take care of these important items.

The Boyden Station

Preliminary tests of the 60-inch reflector were made by Dr. Paraskévopoulos and his assistants during the spring and summer of the current year. It was found necessary to make important alterations in the electric power installation to prevent the operation of the 60-inch reflector, its observing chair, and rotating turret from seriously affecting the operation of the smaller instruments. A new generator has been sent to South Africa and with the help of the city electrical department of Bloemfontein the necessary alterations have now been made and the work during the coming year should progress without serious interruption. The 60-inch mirror has been successfully silvered by Dr. Paraskévopoulos as planned, without removing it from the telescope.

During the months of August and September of this year a serious drought has been attended by dust storms in the Orange Free State. The weather during these usually very good months has been the worst since we went to South Africa in 1927. Notwithstanding the untoward conditions and the temporary decrease in the observing staff, the year's contribution of photographic plates has been exceptionally good. Rapid progress has been made on all programs, and an emergency study with several telescopes of the Large Magellanic Cloud and its environs was carried through without much interruption to the other work.

No provision has yet been made for living quarters to accommodate the assistants at the Boyden Station. Present conditions continue to be very unsatisfactory.

Oak Ridge Station

In September of this year the mounting for the 61-inch reflector was received at Oak Ridge and was erected at once. The observing platform has been made during the year and the machinery for operating the turret and the shutters is now fully installed. We estimate that within three months the 61-inch telescope will be completed and preliminary tests of the mirrors under way. In fact, by January first the whole of the constructional program at Oak Ridge should be completed. During the past year the building for the 8-inch Ross lens, with its accompanying dark-rooms, has been constructed; the Lodge, an eight-room residence, has been built and equipped. A room in the 61-inch building has been made into an optical and instrument shop for Dr. Calder's work on photo-electric photometers and allied problems.

Still ahead of us is the installation of the four new mountings for the patrol cameras on the platform that has been provided for them. The new 8-inch mounting, completed during the year by J. W. Fecker, will soon be installed and while awaiting the manufacture of the Ross lens the Draper 8-inch lens, now in Cambridge, will be transferred to Oak Ridge. When these installations are complete we shall have in systematic use on Oak Ridge nine photographic instruments and, in addition, two visual refractors, one of which is used in connection with the moving "conical mirror" in the study of the velocities of meteors. The observational work on meteors is in charge of Mr. Fletcher Watson, newly appointed assistant in the Department of Astronomy in the College.

The library of the Observatory and the publications are both losing ground as the inevitable result of the restrictions of income. We have been fortunate in getting some special grants for special publications, and friends of the Observatory have helped out in other emergencies. Again this year we have the services of student assistants. In these times of a necessarily restricted computing staff the good work of the student assistants has been greatly appreciated by the Observatory.

There have been no important changes in the work at the Astronomical Laboratory. The number of students, undergraduate and graduate, is practically the same as in recent years. The number of men concentrating in astronomy has, however, increased, and the quality of work is certainly better than it was before the depression emphasized for students the seriousness of education for their future activities.

HARLOW SHAPLEY, *Director.*

EIGHTY-NINTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1934

BY

HARLOW SHAPLEY

CAMBRIDGE, MASSACHUSETTS
PUBLISHED BY THE UNIVERSITY
1935

THE OBSERVATORY

To the President of the University:

Sir, — An important feature of the past year has been the inauguration of work with large reflecting telescopes at both the Boyden and the Oak Ridge Stations. Dr. Paraskévopoulos with the 60-inch telescope at Bloemfontein has begun systematic spectroscopic work on various programs, including the investigation of the motions of early type stars in the Large Magellanic Cloud. A rapid Hilger two-prism spectrograph is in use at the Newtonian focus of the telescope; the large two-prism ultraviolet spectrograph for use at the Cassegrain focus is practically ready for shipment from Cambridge. The 61-inch Wyeth reflector at Oak Ridge has been used steadily since April by Dr. Calder and assistants in various photo-electric programs. The temporary mirror, which will be replaced with a Pyrex disk within two years, proves very satisfactory for photo-electric photometry. It was successfully silvered in June without removal from the telescope.

As is customary during the first year of operation of large telescopes, considerable time has been given to adjustment and alteration of the Harvard reflectors and to the building and attachment of accessories. None of these matters merits special notice, however, except perhaps the difficulties at the Boyden Station arising from the pronounced change of temperature from day to night and its effects on the focus and figure of the glass mirror. Such temperature changes are inevitable in the sites most satisfactory for astronomical work; the difficulties will be much diminished when a mirror of low expansion glass can be provided. The changes in temperature at Oak Ridge are much less bothersome.

The unique mountings designed by Professor Gerrish for the small cameras at Oak Ridge are now set up and are in completely satisfactory operation. Four photographic cameras with focal lengths from six inches to twenty-eight inches are operated from a single rotating shaft. These cameras are involved in systematic sky patrols, standard photometry, special variable star investigations, and in the star counting programs. A new 8-inch mounting was also installed at Oak Ridge during the year, and its new Ross type lens is in operation. A building to be used in meteor observing is under construction at Oak Ridge; it will accommodate a telescope with a

velocity measuring device for the observation of faint meteors and a mirror to assist in the observation of zenithal meteors; it will also provide for direct meteor observations in the northeast and southeast through reticules of the type used on the Arizona meteor expedition.

A general rearrangement of cameras and routine photographic programs has been made during the year, and it is now possible to consider that the Observatory's observational equipment has settled down to a steady state. It may be useful, therefore, to list at this time all the instruments in continual use at the Observatory's three observing stations, indicating also the chief current programs for each instrument.

TELESCOPE	FOCAL LENGTH	PROJECTS
	Cambridge	
	Inches	
15-inch refractor (visual)	269	Asteroidal photometry, variable stars
12-inch polar refractor (visual)	202	Variable stars
12-inch Metcalf doublet	123	Standard red photometry, ecliptic patrol, asteroidal positions
11-inch Draper refractor	153	Proper motions, spectrophotometry, short-period variable stars
8-inch Draper doublet	50	Selected Areas, miscellaneous photometry, variable stars, spectra
6-inch Post refractor (visual)	96	Variable stars
4-inch Voigtländer lens	24	Special variable stars
3-inch Ross-Lundin lens	21	Selected Areas patrol
1½-inch Cooke lens	13	Sky patrol, special variable stars
	Oak Ridge	
61-inch Wyeth reflector	321	Photo-electric photometry, spectroscopy
24-inch Clark reflector	135	Spectrophotometry, photo-electric photometry
16-inch Metcalf doublet	83	Nebular surveys, red magnitudes, variable stars, radial velocities
8-inch Ross-Lundin lens	50	Variable stars, photometry, colors of nebulae, spectra
6½-inch Roe refractor (visual)	102	Miscellaneous
4-inch Cooke lens	42	Nebular photometry
4-inch Ross-Lundin lens	28	Star counts, variable stars
3-inch Ross-Fecker lens	21	Standard photometry, Selected Areas patrol, nebulae
1½-inch Cooke lens	13	Sky patrol
1¼-inch Ross-Xpres lens	6	Sky patrol

Bloemfontein

60-inch reflector	314	Spectroscopy, globular clusters, nebulae
24-inch Bruce doublet	135	Nebular survey, proper motions, variable stars, red magnitudes, asteroids
13-inch Boyden refractor	205	Spectrophotometry, proper motions, star clusters
10-inch Metcalf triplet	45	Variable stars, objective prism spectra
8-inch Bache doublet	44	Variable stars, standard photometry, star counts
3-inch Ross-Fecker lens	21	Sky patrol, photometry, star counts
3-inch Ross-Tessar lens	12	Nebular photometry
1½-inch Cooke lens	13	Sky patrol

In addition to the foregoing there is equipment used occasionally, such as the Russian Transit of the Boyden Station, the two "Lilliputian" telescopes of five-inches focal length operated at the Oak Ridge Station in photography of the surface brightness of the Milky Way, the meteor cameras and the telescopic meteor observing equipment, also at Oak Ridge, and the spectrohelioscope which has been installed on the Observatory grounds in Cambridge by Dr. J. C. Boyce of the Massachusetts Institute of Technology. Finally, there is the 7½ inch Agassiz Telescope at the Students' Astronomical Laboratory on Jarvis Street in Cambridge that is used for a daily photograph of the solar surface — a routine maintained in coöperation with the Naval Observatory in Washington.

With the assistance of a grant from the J. Lawrence Smith Fund of the National Academy of Sciences, we have maintained throughout the year a small computing bureau in Tartu, Estonia, where our observations of meteors are being reduced and discussed under the general supervision of Dr. Öpik. In another year the work will be completed.

In the death of Dr. Willard J. Fisher in September the Observatory lost an important worker in the field of meteor astronomy. Dr. Fisher's influence on the graduate students will long be remembered. Fortunately the more important part of his research work had been brought to a conclusion during the past year. His record of productivity during his eleven years' association with the Harvard Observatory is a highly creditable one.

Dr. Theodore E. Sterne has joined the staff of the Observatory and the Department of Astronomy as Lecturer on Astrophysics. His current studies are chiefly in the field of statistical methods and their application to problems in variable stars and in stellar distribution.

Dr. Sergei Gaposchkin has been at the Observatory during part of the year as special Research Assistant. He has paid particular attention to problems of variable stars and to researches in photometry.

Mr. Sidney W. McCuskey, of the Warner and Swasey Observatory, Cleveland, Ohio, has come to Harvard as Assistant in the Department of Astronomy; Miss Rebecca Jones has been appointed Pickering Fellow. A special bequest to the Observatory from Earl Willson Bemis, of Worcester, Massachusetts, has made it possible to provide astronomical work for four advanced students in astronomy. The Bemis Assistants this year in Cambridge are Carl K. Seyfert (Harvard) and James Cuffey (Dearborn Observatory). The Bemis Assistant Observers at Oak Ridge are John W. Evans (Flower Observatory) and Leo Goldberg (Harvard).

The usual number of Harvard *Circulars* and parts of Harvard *Annals* have been issued during the past year, but the appearance of the *Bulletins* has been less frequent than heretofore because of restricted publication budget. In the various Harvard Observatory series of publications a total of forty six titles by twenty-four members of the staff have appeared. The Observatory has cooperated with the Bond Astronomical Club in taking over the publication of an illustrated bi-monthly journal of astronomy, entitled *The Telescope*. Dr. L. B. Andrews, executive secretary of the Observatory, has assumed chief editorial responsibilities of the new journal.

The facilities of the Observatory have been extended as heretofore to the members of the Bond Astronomical Club, which holds monthly meetings in the library. A new society, the Boston Telescope Makers, also meets regularly at the Observatory in Building A. Both of these groups assist the Observatory staff in the conduct of the short series of open nights in the fall and spring of each year.

HARLOW SHAPLEY, *Director.*

NINETIETH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1935

BY

HARLOW SHAPLEY

CAMBRIDGE, MASSACHUSETTS
PUBLISHED BY THE UNIVERSITY
1936

Observatory

To the President of the University:

Sir, — For the first time in its history the Harvard Observatory has taken active part in graduate work during the summer. The Graduate Summer School of Astronomy and Astrophysics was inaugurated this year with the aid and under the direction of the Harvard Summer School of Arts and Sciences. The experiment of offering advanced lectures and opportunities for research under the direction of specialists in the various fields of Astronomy attracted wide-spread attention. The staff included Dr. Antonie Pannekoek, astrophysicist of the University of Amsterdam, Dr. Otto Struve, director of the Yerkes Observatory of the University of Chicago, Dr. Ira S. Bowen of the California Institute of Technology, and Dr. Olin C. Wilson of the Mount Wilson Observatory. Several members of the Harvard Observatory staff participated in the seminars and colloquia, and two former Harvard graduate students — Dr. Freeman D. Miller and Dr. Peter M. Millman — were called back to take part in the undergraduate astronomical work. The seminars in various fields of Astronomy and Astrophysics proved to be of high value not only to the graduate students at Harvard but also to visiting instructors and investigators from other institutions. Plans have been made for a similar summer session in 1936.

The work at the Boyden Station during the past year has included activity in several new programs in spectroscopy and photometry. The general proper motion survey is nearly completed, and extensive progress has been made on the survey for variable stars in high galactic latitudes. During the month of June 1935, a new monthly record was set when 923 photographs were made — the work of eight telescopes.

Equipment constructed during the past year includes a 20-inch reflecting telescope, of which the focal ratio of the principal mirror has the unusual value of 2.2, and a new densitometer, made by David Mann of Cambridge. The 20-inch reflector is installed at the Oak Ridge Station and is used by Dr. Calder with a photoelectric photometer. The densitometer, which is built to work also as a measuring engine, has been used chiefly by Professor J. C.

Boyce and Dr. Carol A. Rieke in spectroscopic measurements. It will be employed later in densitometric work on objective prism spectra and in the problems of the diameters and light distribution of clusters and external galaxies.

A two-prism ultraviolet spectrograph for use at the Newtonian focus of the Wyeth reflector at Oak Ridge has been constructed by Carl Heinrich of Somerville, following designs by Dr. Whipple and Dr. Menzel. The instrument has been used during the year in problems of radial velocity and spectrophotometry, including a special series of ultraviolet spectrograms for Dr. Pannekoek's researches on the forms of spectral lines in typical stars.

Assisted by a grant from the Milton Fund of Harvard University, the Observatory is making plans for an expedition to Siberia to observe the solar eclipse of June 19, 1936. The expedition will be made in coöperation with the Massachusetts Institute of Technology and will be under the leadership of Dr. D. H. Menzel of the Observatory staff. Loans of important equipment have been made by various manufacturers and observatories. We are especially indebted to the Lick Observatory for the loan of extensive equipment that has been used for earlier eclipses. Dr. Boris P. Gerasimovič, formerly an associate at the Harvard Observatory and now director of the Poulkovo Observatory, is arranging all details for the expedition after it reaches Russia. A site has been chosen on the central line of totality, ten miles from Akboulak. It is probable that the Harvard expedition will be joined by one from Poulkovo and another from Arcetri, Italy. Extensive programs of spectroscopic work on the corona and chromosphere are planned, as well as experiments on the effect of radio reception of the passing of the moon's shadow over the earth.

There have been few changes in the staff during the past year. Miss Sylvia F. Mussells (Mrs. Lindsay), an assistant in the nebular department, has been transferred to the Boyden Station, where she continues work on the long exposure Bruce photographs of external galaxies. Miss Rebecca Jones, Pickering Fellow of last year, has entered the nebular department and will give special attention to the distribution of faint galaxies north of declination $+70°$. The Meteor Computing Bureau at Tartu, Estonia, continues under the direction of Dr. Öpik, but the discussion of the Arizona results is now nearing completion.

The Bemis Assistants for the coming year are John W. Evans (Flower Observatory), Henry H. Hemmendinger (Harvard), and

George Z. Dimitroff (Colorado). Assistants at the Students' Astronomical Laboratory on Jarvis Street will be Fletcher G. Watson, Jr., Leo Goldberg, and James Cuffey. At the Boyden Station Mr. Nicholas Ferreira, who has been an assistant for several years, has resigned because of ill health.

In accordance with the custom of recent years, reference to the many research programs is omitted. Publications have been more numerous and extensive than in the preceding year, and the Observatory's limited publication budget is overtaxed. A new plan for the publication of the spectra of faint stars classified by Miss Cannon as a part of the work of the Henry Draper Memorial will result in a considerable saving in expense and time. Hereafter most of the faint spectra of the "Henry Draper Extension" will be published on reproductions of photographic plates (not in tabular catalogues); on each reproduction the spectra will be numbered and the spectral class (also sometimes the magnitude) will be shown. The stars will not be specifically identified with catalogue stars, nor will the positions be determined. It is estimated that five to ten times as many spectra can be published each year without seriously decreasing the value of the results for statistical analyses. These new "Henry Draper Charts" will be printed, as are now many of the long tables in the *Circulars* and *Annals*, by the economical planograph (photo-lithographic) process.

A total of fifty seven titles by twenty six members of the staff have appeared during the year in the *Bulletins*, *Circulars*, *Annals*, and *Reprints* issued by the Observatory. In addition there have been distributed to special groups of investigators or selected observatories nine *Mimeograms*, containing chiefly variable star predictions and preliminary magnitudes from the extensive photometric catalogues that are now in progress. Also, forty *Announcement Cards* have been issued, fifteen of which contain reports of observations or computations by members of the Observatory staff.

As we look toward the future, it appears that one of the most definite needs of the Observatory is a special endowment to cover the expenses of publication.

HARLOW SHAPLEY, *Director.*

NINETY-FIRST

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1936

BY

HARLOW SHAPLEY

CAMBRIDGE, MASSACHUSETTS
PUBLISHED BY THE UNIVERSITY
1937

[*From the Report of the President of Harvard University, 1935–36*]

Observatory

To the President of the University:

Sir, — It is a pleasure to report that the eclipse expedition to Russia was thoroughly successful. From a scientific viewpoint the total solar eclipse of June 19 is the most outstanding event in a year that has been conspicuous for interesting astronomical phenomena. The success of the expedition was twofold. Under Dr. Menzel's competent leadership an elaborate program had been planned and notwithstanding the usual difficulties and emergencies that arise when scientific specialists work hastily in a remote foreign country, the outlined program in its many details was carried through practically without a slip. The weather, after threatening disaster on the eclipse morning, cleared beautifully. The second way in which the eclipse expedition has succeeded is in its solvency. Thanks to the Milton Fund for a major grant and to various academies, individuals, and manufacturers for grants of money or equipment, it has been possible to carry through the expedition without cramping the regular activities of the Observatory. Dr. Menzel and his collaborators brought back from Russia several hundred excellent spectrograms which cover the solar spectrum from the ultraviolet to the extreme infrared. The preliminary examination shows a number of new coronal lines, but a full evaluation of the results will require many months of close analysis.

The Harvard Tercentenary brought special labors and opportunities to the Observatory. With aid from the Tercentenary Exhibits fund, Dr. Andrews carried through a complete overhauling of the Observatory exhibits, and added several new features, including models of the Boyden Station at Bloemfontein and the Oak Ridge Station in Harvard. These exhibits, which included illustrations of the Observatory's researches, were supplemented by three excellent models of stars and star groups, especially built for the occasion and lent to the Observatory by the Buffalo Museum of Science. The new exhibits were distributed throughout several rooms in the Observatory and were available for the special series of Open Nights maintained during the summer of 1936, for the guests of the Harvard Tercentenary Conference, the astronomers in attendance

at the Harvard meeting of the American Astronomical Society, and the Harvard alumni and other delegates to the Tercentenary Celebration in September.

Following the successful experiment in the summer of 1935, the Observatory again operated a Graduate School of Astronomy and Astrophysics, in coöperation with the Harvard Summer School. Members of the visiting faculty included Dr. Knut Lundmark of Lund, Sweden, Dr. Rupert Wildt of Göttingen and Princeton Universities, Dr. Paul W. Merrill of Mount Wilson Observatory, Dr. Meg Nad Saha of Allahabad University, India, Professor Henry Norris Russell of Princeton University, Professor Frank Schlesinger of Yale University, and Dr. Piet van de Kamp of the University of Virginia.

For a feature of the Harvard Tercentenary, the members of the staff of the Observatory prepared a series of approximately thirty papers, all reporting on current researches. A selection of these papers was presented as the entire morning program of the American Astronomical Society on September 4, 1936. It is proposed to print most of the papers together in a single volume of the Harvard Annals — the Tercentenary Volume. Among the contributions will be Miss Cannon's first instalment of charts of stellar spectra — some twenty-nine hundred new classifications presented on nine photographic charts; Dr. Bok's report of the pioneer work he has carried out with Dr. McCuskey on the radial velocities of stars; Dr. Calder's new photo-electric measurements of the brightness of Sun and Moon; the detailed analysis by Dr. Sterne and Mr. Campbell of the periods of long period variable stars; photographs of southern clusters and nebulae by Dr. Paraskevopoulos; Miss Hoffleit's determination of the absolute magnitudes of bright southern stars; the extensive investigation of meteoric problems by Dr. Öpik, Dr. Millman, Mr. Watson, and Miss Hoffleit; studies of galaxies by Dr. Shapley, Dr. Seyfert, and Miss Mohr, and of variable stars by Dr. Sergei Gaposchkin, Miss Swope, Miss Harwood, Mr. Baker, and Miss Boyd. Dr. Luyten writes on proper motions, Mr. Cuffey on star clusters, Mr. Dimitroff and Dr. Menzel on the new microdensitometer, Dr. Bok and Dr. Lindsay on stellar distribution, Mr. Greenstein on Milky Way structure, and Dr. Whipple and Mr. Cunningham on the orbit of the peculiar asteroid Apollo.

During the year the 61-inch Pyrex mirror for the Wyeth reflector at Oak Ridge has been completed by Mr. Fecker of Pittsburgh and

is soon to be installed. For the past three years we have successfully used the temporary mirror, but the problems suited to its imperfect surface are limited. A large objective grating has also been made for this telescope to be used in the studies of the colors of external galaxies and especially in the search for high latitude blue stars. By removing every other rod from the grating, we change its characteristics in such a way that it becomes useful for the standardization of stellar magnitudes among faint stars.

New equipment completed during the year includes a 10-inch reflector, adapted for experiments in radiometry which are being carried on by Dr. Sterne and Dr. Emberson. The 10-inch is mounted in Cambridge, and in part involves equipment provided by Mr. C. W. Elmer. At the conclusion of the preliminary experiments the thermal equipment will probably be transferred to the Wyeth reflector at Oak Ridge.

At the Boyden Station a new mounting for the 8-inch Bache lens has been installed. Dr. Paraskevopoulos has carried through an investigation of the driving mechanism for the 10-inch Metcalf telescope and finds serious difficulty with the worm-wheel. When this trouble has been eliminated, we expect a definite improvement in the quality of the plates on faint southern variable stars. Dr. Paraskevopoulos has adapted the 13-inch Boyden refractor to the problem of objective-prism radial velocities and an important field is thus opened for an instrument otherwise not much used in our current programs.

If judged by the number of photographs made, the past year has been better than the average; but the unusually large number of plates is in part to be attributed to the nature of the photometric programs. The budget is beginning to feel the pressure of the extensive purchases of special plates. The most serious budgetary difficulty, however, lies in the problem of meeting the expenses of printing. The scientific productivity of the members of the staff is pleasant to contemplate until the bills for the Observatory publications come in. It is to be hoped that the University will be able to give assistance to the departmental publications, or in some way provide aid so that we shall not be forced to discourage scientific activity solely because of inability to publish the results properly.

There have been no major alterations in the staff. Dr. S. W. McCuskey, formerly assistant in Astronomy and Agassiz Research Fellow, has become an assistant professor in the Case School of Applied Science, Cleveland. Dr. Carl K. Seyfert, Parker Fellow,

has joined the staff of the McDonald Observatory in Texas. The nebular department has lost the services of Mrs. Muriel M. Seyfert who for several years has worked expertly on the discovery and measurement of external galaxies. Dr. Carol A. Rieke, for a number of years a research associate at the Harvard Observatory, is now at Johns Hopkins University, but she continues the use of Harvard plates in her study of the absolute magnitudes and distances of stars in galactic clusters.

The Bemis Assistants for the coming year are Leo Goldberg (Harvard), Dr. Richard M. Emberson (Missouri), and Mr. Henry Hemmendinger (Harvard). Assistants at the Students Astronomical Laboratory on Jarvis Street are George Z. Dimitroff, Frank K. Edmondson, and John W. Evans.

Dr. Loring B. Andrews has been granted a leave of absence from the Department of Astronomy for one year in the interests of projects in educational broadcasting. During his absence Mr. Fletcher G. Watson, Jr. acts as instructor at the Astronomical Laboratory.

The publications issued by the Observatory during the past year include a total of eighty-one papers by thirty members of the staff published in the *Bulletins*, *Circulars*, *Annals*, and *Reprints* of the Observatory. The unusual number of novae during the year has necessitated much telegraphic service and the issuance of forty-one Harvard Announcement Cards.

HARLOW SHAPLEY, *Director.*

NINETY-SECOND

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1937

BY

HARLOW SHAPLEY

CAMBRIDGE, MASSACHUSETTS
PUBLISHED BY THE UNIVERSITY
1938

Observatory

To the President of the University:

Sir, — The Observatory's progress in both observational and theoretical fields of astronomy during the past year has been steady and fruitful. Volume 105 of the Observatory Annals, the Tercentenary Volume, has been published. It contains thirty-four papers by thirty-six members of the staff and associates. The nature of the researches involved was described in the preceding Annual Report. Many of the investigations have been continued during the current year. Studies in photometry and in variable stars, analyses of the distribution and structure of galaxies, and investigations of Milky Way problems are among the developments continuing from the work presented in the Tercentenary Volume.

The Harvard Summer Conferences on Astronomy were held during the Summer Session of the University, as before. Among the visiting lecturers were Dr. H. P. Robertson of Princeton, Dr. Brian O'Brien of the University of Rochester, Dr. Dirk Brower of Yale, Dr. Dean B. McLaughlin of the University of Michigan, Dr. Bengt Edlén of the University of Upsala, Sweden, and Dr. John C. Slater of the Massachusetts Institute of Technology.

A number of coöperative enterprises with other observatories are in progress. An extensive photographic program is in progress with the 8-inch telescope in Cambridge, to furnish material for investigations by Dr. P. J. van Rhijn, Director of the Kapteyn Astronomical Laboratory at Groningen, Holland. Dr. Freeman D. Miller of Denison University, and Dr. Sidney W. McCuskey at the Case School of Applied Sciences in Cleveland, Ohio, are also using Harvard Plates in coöperative research programs. Dr. Miller is studying the galactic structure from Cygnus to Scutum; Dr. McCuskey is analysing the Milky Way in the neighborhood of Taurus. Dr. Leah B. Allen, at the Williams Observatory of Hood College, Frederick, Maryland, has undertaken a study of one of the Harvard variable star regions in high galactic latitude — a part of an attack on the problem of the dimensions of the Galaxy.

During the past year we have been very successful in the photographing of meteors from two stations — Cambridge and Oak

Ridge. A patrol camera at Oak Ridge is equipped with a rotating shutter, designed as to dimensions and speed to record interruptions of whatever meteor trails may be photographed during the regular stellar work. A similar camera is operated from Cambridge, and the programs synchronized. A dozen bright meteors have been doubly photographed and the analysis of the results will give us information on altitudes, velocities, orbits, and the decelerations of particles moving through the upper atmosphere.

Dr. Menzel and Mr. French have been making a special study of the problem of observing the solar corona outside of total eclipse. The corona cannot be seen ordinarily because of the brightness of the sky in the neighborhood of the sun. The problem, then, is to find a method for eliminating sky glare. Two methods for accomplishing this result are being tried. First, television procedure is applied to the scanning of an image of the sun plus the glare. The resulting photo-electric current is amplified, but the major portion is suppressed electrically. The remainder, a small fraction of one per cent, which is presumably due to coronal light, is further amplified and used to excite a glow lamp. An image is then built up from the glow lamp on a moving film synchronized with the initial scanning system. Laboratory tests have shown that glare amounting to more than one thousand times the light of the initial image can be completely eliminated, but the solar observation presents a greater problem because the glare is radially symmetrical and not uniform. A new type of radial scanning system is being devised to replace the present linear scanning system. A second method of eliminating glare, by means of a spectrograph, which is now used successfully by Lyot in France, will be tested.

The 60-inch reflector at the Boyden Station during the past year has provided plate material for a number of investigations of bright and faint galaxies, globular clusters, and variable stars. The new mirror of the 61-inch Wyeth telescope at Oak Ridge has been installed and is in use on both extra-galactic and radiometric work. A reducing lens is being adapted for this instrument, to facilitate work on external galaxies and clusters.

Dr. William A. Calder, resident astronomer at the Oak Ridge Station, has left the Observatory to assume a professorship at Knox College, Galesburg, Indiana. Dr. George Z. Dimitroff has taken Dr. Calder's place at Oak Ridge, and will continue the photo-electric work. Dr. Eric M. Lindsay, who for three years has been observer at the Boyden Station, Bloemfontein, South

Africa, has resigned to become director of the Armagh Observatory, Armagh, Ireland. Dr. Lindsay is planning to continue his work on the structure of the Milky Way which he has carried on in coöperation with Dr. Bok. Harvard photographs taken at the Boyden Station for this program will be used by Dr. Lindsay at Armagh. Dr. Frank K. Edmondson, Assistant in Astronomy, has accepted a position at the University of Indiana where he will take part in the installation and use of a 24-inch Schwarzschild-type reflector.

Miss Florence Cushman, who entered the Observatory as a computer in 1888, has retired from her post as assistant to Professor Gerrish. Dr. Martin Schwarzschild of Göttingen has joined the staff of the Observatory and at present is concerned with the problems of Cepheid variation. The Agassiz Research Fellow for 1937–38 is Mr. Leo Goldberg. Assistants newly appointed at the Students' Astronomical Laboratory are James Cuffey, W. A. Johnson, and John A. O'Keefe. Mr. Fletcher G. Watson, Jr., is again instructor in practical astronomy at the Laboratory in the place of Dr. Andrews who continues on leave of absence in order to act as program director for the World Wide Broadcasting Foundation.

During the course of the past year seventy-nine papers by forty-four staff members and associates have been published in the Observatory's *Annals*, *Bulletins*, and *Circulars*. Brief announcement of current discoveries, for which the Observatory serves as a telegraphic clearing-house, has been made in a series of thirty-nine *Announcement Cards*.

HARLOW SHAPLEY, *Director*

[*Reprint from the Report of the President of Harvard College, 1936-1937.*]

NINETY-THIRD

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1938

BY

HARLOW SHAPLEY

UNIVERSITY OF ARIZONA
STEWARD OBSERVATORY

CAMBRIDGE, MASSACHUSETTS
PUBLISHED BY THE UNIVERSITY
1939

Observatory

To the President of the University:

Sir, — The inauguration of the Milton Variable Star Bureau has been an important development of the Observatory during the past year. Supported for a period of two years by a grant from the Milton Fund of Harvard University, the work of this Bureau is designed to furnish a homogeneous study of all known variable stars brighter than the eleventh magnitude. Thousands of photographic plates in the Harvard collection are being studied and half a dozen assistants, under the direction of Dr. Cecilia Payne-Gaposchkin and Dr. Sergei Gaposchkin, are making the necessary measures and reductions. The program includes the investigation of about two thousand variable stars, on which more than three million measures must be made.

A second special bureau that can report good progress during this year is the one supported through grants made by the University from resources provided by the Associates of the Physical Sciences for work on external galaxies and the related problems of our own Milky Way. These researches have been greatly expedited through the special provision of photographic material and of technical assistants. During the year about two thousand astrophotographs have been made at the Observatory's three observing stations in the interests of the work. The Bureau's activities have been divided into two overlapping parts — the study of faint and distant variable stars, and the survey of external galaxies. The study of the variable stars has permitted the derivation of new results on the dimensions of the Milky Way system. It produced confirming evidence for the earlier discovery that the Milky Way is surrounded by a very extensive low-density atmosphere of stars. The exploration of galaxies has included a concentration on certain significant regions of the sky in order to extend our knowledge of the density gradients which appear to be important features of cosmic structure. The galaxies have also been used as a means of finding those regions along the Milky Way that are free from space absorption. As a by-product, the discovery of a new type of stellar system, which is being investigated with the help of the southern 60-inch reflector, has opened possibilities of understanding more clearly the structures of external galaxies and the evidences of evolutionary development.

The number of new galaxies detected on the Harvard plates now exceeds four hundred thousand; the survey to the eighteenth magnitude is essentially half completed. Reports on the methods and progress of the survey, and on the results obtained, were made at the International Astronomical Union meeting in Stockholm in August, 1938, and at the meeting of the British Association for the Advancement of Science in Cambridge, England, in the same month.

It has become very clear to the investigators at the Observatory who are concerned with problems of the Metagalaxy, of faint variable stars, of star counts as a means of analysing the structure of the Milky Way, and of standards of stellar magnitudes, that the Observatory's equipment must be enlarged by the construction of powerful Schmidt-type telescopes. The new Schmidt design overcomes the handicap of the small field of conventional reflectors and the chromatic troubles and other difficulties that accompany the use of large-field refractors. It makes the reflector an important and effective instrument for survey work.

During the year the 12-inch Metcalf refractor was moved from the grounds in Cambridge to Oak Ridge. The transfer has already yielded a great increase in the effectiveness of the telescope. With the clearer atmosphere at the out-of-town station, the instrument is a valued addition to the equipment for systematic programs. It is being used to augment the observational material for the study of high-latitude variable stars, and, during the light of the moon, to obtain red photographs on variable stars and for other problems. A study of the structure, density distribution, and diameters of galaxies on the basis of densitometer tracings of photographs taken with this 12-inch telescope has been begun by one of the graduate students. Dr. Dimitroff is also using the instrument in the determination of star colors by means of photographs in red and blue light. If this particular method is successful, it will be used in a further attack on the problem of distant stars in high latitude — a part of the study of the structure of the Milky Way.

The study of meteor trails on simultaneous photographs made at the Cambridge and Oak Ridge stations has contributed considerably during the past year to knowledge of heights and linear speeds. The installation of a "meteor trail chopper" on the Cambridge meteor camera permits a more complete study of the deceleration of meteors, and has enabled Dr. Whipple to deduce temperatures and densities in the upper atmosphere.

The coöperative work carried on with a number of other observatories, chiefly under the guidance of Dr. Bok, has continued throughout the year. Work on the solar coronagraph is progressing. The equipment has not yet been completely built, but is expected to be finished during the coming year. Radiometric work by Dr. Sterne and Dr. Emberson has been continued with the use of the 61-inch Wyeth reflector at Oak Ridge. Also with this instrument the solar brightness is being compared with the brightness of stars.

In recent years there has been an increasing activity at the Observatory in theoretical studies. The problems of Cepheid variation and of eclipsing binaries have received special attention from Dr. Schwarzschild, Dr. Sterne, and Dr. Kopal, while theoretical work in astrophysics, especially in problems of planetary nebulae and the solar atmosphere, has been advanced by Dr. Menzel, Dr. Goldberg, Dr. Spitzer, Mr. Baker, and Mr. Aller.

The major change in staff during the past year was the retirement in July of Professor Willard P. Gerrish. For more than fifty years he had been a member of the staff of the Observatory. He had charge of the telescopic equipment and of the machine shop, and acted as general business manager. The mechanical equipment of the Observatory at all of its stations owes more to Professor Gerrish than to any other one individual. Dr. Fletcher G. Watson has been appointed Executive Secretary of the Observatory, with general responsibility for the business management and as general assistant to the Director. Dr. George Z. Dimitroff supervises the Oak Ridge Station and the photographic telescopes at the Cambridge headquarters, as well as the Observatory shop.

Research Associates at the Observatory during all or part of the past year are Professor Robert H. Baker of the University of Illinois, Dr. Chaim L. Pekeris of the Massachusetts Institute of Technology, and Dr. Y. Hagihara of the Imperial University of Tokyo.

During September and October the Director visited the South African station of the Observatory. The instruments and buildings of the station are in good condition and a high degree of efficiency is maintained in the scientific work. The personnel of the station now includes, in addition to the Superintendent, Dr. John S. Paraskevopoulos, five observers (all South Africans), one mechanic, and five Basuto workmen. The station collaborates on observational problems with the Royal Observatory at the Cape of Good Hope and with the University of Witwatersrand, Johannesburg.

The principal interests, of course, are the programs on southern stars and nebulae as outlined at the headquarters in Cambridge. During the past year more than five thousand glass negatives were made with the nine different instruments, which range in aperture from the patrol camera of a little more than an inch in diameter to the 60-inch reflector, the largest telescope in operation in the southern hemisphere.

The Summer Conference on Astronomy and Astrophysics was not held at the Observatory during 1938, as a large number of the Observatory staff attended the triennial meetings of the International Astronomical Union in Stockholm, held from August 3 to August 10. The scientific conferences included papers by Dr. Shapley, Dr. Menzel, and Dr. Bok. Twelve of the Observatory staff are members of thirteen of the special Commissions of the Union.

The Cambridge Station was not badly damaged in the September hurricane. The shutter blew off the 15-inch dome, some copper roofing was destroyed, and one chimney fell in. Many of the large trees on the grounds were uprooted. At Oak Ridge, however, the damage to trees was severe, though the buildings escaped serious injury. It is estimated that clearing up the forest and repairing the roofs will cost two thousand dollars.

During the year thirty-two papers were published in the Observatory's Annals, Bulletins, Circulars, and Reprints, by thirty-one authors. There were sent out twenty-nine Announcement Cards — a part of the Observatory's activity as clearing-house for the announcement of new discoveries.

HARLOW SHAPLEY, *Director*

[*Reprinted from the President's Report for 1937–1938.*]

NINETY-FOURTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1939

BY

HARLOW SHAPLEY

CAMBRIDGE, MASSACHUSETTS
PUBLISHED BY THE UNIVERSITY
1940

[*Reprinted from the Report of the President of Harvard College and Reports of Departments, 1938–39*]

Observatory

To the President of the University:

Sir, — The need of the Observatory for large-field reflecting telescopes in its various researches was noted in last year's Report. It is our good fortune that friends of the Observatory have promptly made it possible for us to develop our instrumental facilities in the desired direction. A transformation of our southern reflector from the conventional parabolic type to the Schmidt type is now under way. One of the most powerful instruments in the world will thus be at our disposal. A year from now may see the transformation completed, although the disruption of industry and commerce by the European wars may somewhat delay the work. Since it is equally important to have a Schmidt-type reflector available for our researches in the north, we have proceeded with the construction of a 24-inch Schmidt reflector for the Oak Ridge Station. The construction of the mounting in our own shop and of the piers and floors at Oak Ridge is progressing steadily under the direction of Dr. George Z. Dimitroff, superintendent of the Oak Ridge Station. The optical parts, which include a 24-inch correcting plate and a 33-inch Pyrex mirror, are under construction by the firm of Perkin, Elmer & Moffitt of New York. The funds necessary for making this important Oak Ridge telescope come partially from the balance of the Rockefeller gift of ten years ago, which was contributed in part for the development of the Oak Ridge Station. The instrument is also partially financed through special economies in the regular Observatory budget, such as delay in the filling of a vacancy in the computing staff, economies in publication, and the like. But the project is still not completely financed and additional funds are needed for the building to house this powerful reflector when completed.

Many important research problems can be prosecuted with greater effectiveness when these two Schmidt-type telescopes are completed. The southern instrument will be especially useful in the studies of galaxies, variable stars, the structure of the Milky Way, and the classification of faint spectra; the northern will supplement the Metcalf refractor for similar researches, and go farther.

For many years the Observatory has attempted to take a part in the general community life of Cambridge and the surrounding

cities and towns. During the past year this public service has been continued. It may be of interest to cite some of the specific ways in which the Observatory tries to respond to the public interest in astronomy and allied subjects.

a. In collaboration with the Dowse Institute of Cambridge a series of seven free Open Nights were held at the Observatory during the summer. At each of these special sessions, attended by three hundred to five hundred persons, two lectures were given, a dozen members of the staff guided the visitors through the Observatory, and telescopes were put at the disposal of those who were inclined to observe the heavenly bodies.

b. The Bond Astronomical Club, an organization for the public, but including amateur and professional astronomers, held its eight meetings at the Observatory.

c. The Amateur Telescope Makers of Boston held their numerous meetings at the Observatory and made continuous use of the basement rooms under Building A for their machine and optical shop in which lenses and mirrors are ground and tested and other telescopic accessories developed and built.

d. The Harold C. Ernst collection of portable sundials, acquired over a year ago by the Observatory, has been skilfully overhauled and put on display by Mr. and Mrs. R. N. Mayall. The collection is perhaps the most important in existence that is on public exhibition, and its many unique items always attract much attention from visitors to the Observatory.

e. Throughout several months of the winter public open nights are held on every second Friday for the school children of the community. During the year hundreds of children came from more than twenty schools, private and public, for a tour of the Observatory exhibits, a popular lecture on astronomy, and observation through the historical 15-inch telescope. Connecticut, New Hampshire, and Rhode Island schools have sent science classes and other visitors to the Observatory for these open nights. The Cambridge public schools have unfortunately made much less use of these opportunities than we had hoped. In the spring and autumn, series for adults are organized and are always heavily attended.

f. An illustrated popular bimonthly magazine of astronomy is published at cost at the Observatory in coöperation with the Bond Astronomical Club. Some members of the staff, especially

Dr. D. H. Menzel and Dr. Leo Goldberg, devote much time to the production of this convenient and useful contribution to public education.

Personnel changes during the year have not been numerous in the regular staff. After three years as a Research Fellow, Dr. Richard Emberson has left the Observatory to undertake research work in physics in Pittsburgh, Pennsylvania. During his stay at the Observatory he helped in the development of the radiometric equipment for the Wyeth reflector at Oak Ridge and used the equipment in the determination of an important series of radiometric magnitudes of the brighter northern stars. Miss Lillian Hodgdon, who had been at the Observatory for half a century and who in recent years had been assistant curator of the photographic library, retired in July.

The purge of many intellectuals by the Central European totalitarian states has resulted in providing the Harvard Observatory with worries, and with personnel gains. At least temporarily at the Observatory are Dr. Richard Prager of Berlin, Dr. Luigi Jacchia of Bologna, and Dr. Zdeněk Kopal of Prague — all of them active investigators in astronomical fields cultivated at the Observatory. Dr. Prager has recently resumed his important bibliography and history of variable stars, partially supported by the International Astronomical Union. Dr. Jacchia has assisted in the Milton Bureau and carried on other investigations of variable stars, both photographically and visually. Dr. Kopal, who originally came to the Observatory as a government research fellow from Czechoslovakia, continues his investigations of star clusters, proper motions, and the orbits of eclipsing binaries. At the Boyden Station there have been no important changes in personnel during the past year, but since several of the younger members of the staff are military reservists there is unfortunately some likelihood that the station may become shorthanded during the coming year.

In addition to the work on the Schmidt telescopes the only major instrumental construction has been the progress of Dr. Menzel and his associates in the construction of the coronagraph for the study of the solar atmosphere. During the past summer Dr. Menzel visited a number of high locations in Colorado as possible sites for efficient and continual use of the coronagraph after it has been thoroughly tested at the lower altitude of Oak Ridge.

Mr. J. G. Baker has practically completed his large spectrograph

NINETY-FIFTH

ANNUAL REPORT

OF THE

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THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1940

BY

HARLOW SHAPLEY

CAMBRIDGE, MASSACHUSETTS
PUBLISHED BY THE UNIVERSITY
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Observatory

To the President of the University:

Sir, — As in many other parts of the University, the work of the Observatory has been little disturbed by more than a year of the European conflict. An important branch of the Observatory is within the British Empire, and several times during the past year valuable shipments of photographic plates have been sent from South Africa to America. We have suffered no losses, and very few delays, either in freight shipments or in communications by mail and radio.

Nevertheless, we have not remained wholly untouched. Mr. E. E. Steyn, chief assistant, resigned from the Observatory's southern station in December, 1939, to take a commission as second lieutenant in the army of the Union of South Africa. Later in the year two others from our observing staff there, C. C. Easby (private) and F. R. de Villiers (sergeant) left to join the military forces. In keeping with the custom of the country, we immediately arranged that the salary differences would be paid by the Observatory to the families of the men who had left for military work, and that their places on the staff of the Observatory would be kept open. Three young women have been employed temporarily as observers; their work has been remarkably satisfactory, notwithstanding the fact that they joined our staff for work on heavy schedules during the long cold nights from June to September.

The quality and quantity of the systematic astrophotographic work carried on at the Boyden Station during this past year has not been excelled at any time. The somewhat higher expense for materials has been offset by the low price of the South African pound. In addition to Dr. Paraskevopoulos, superintendent of our southern station, the personnel comprises six observers, a mechanic, and five natives who work on the grounds, help take care of the instruments, assist with the receipt and despatch of shipments, and maintain the road up the side of Harvard Kopje.

An outstanding event in the history of the Harvard Observatory has been the establishment this year of the high-altitude station for solar research in Fremont Pass, Climax, Colorado. Dr. Donald H.

Menzel, who has been in charge of the work of building the station, spent four months during the past summer in Colorado. Mr. Walter O. Roberts has remained at Climax to carry on the details of installing the coronagraph, completing the tests, and inaugurating systematic studies of solar phenomena.

The building of our station at this favorable site, 11,500 feet above sea level, would not have been possible without the persistent and enthusiastic interest of Mr. Max Schott and his colleagues in the Climax Molybdenum Company. Not only have the Company and many of its officers made generous gifts to finance the building of the station, but the engineers and others associated with the Company have skilfully carried through the construction of our rather unusual observatory building. In addition to the assistance from the Climax Molybdenum Company and its officers we have received important gifts from The Dow Chemical Company, The Owens-Corning Glass Company, The Public Service Company of Colorado, Mr. Mahlon Thatcher, and many others.

The chief work of the Climax Station, especially in the beginning, is to use our newly constructed coronagraph, which closely follows the type developed in France by Bernard Lyot, for direct and spectrographic studies of the corona and solar prominences. It is too early to give a report on the ultimate possibilities of the instrument in this high altitude, but already we can say that we have before us for daily investigation those evasive atmospheres of the Sun which ordinarily are available only at the time of total solar eclipses.

In last year's Report the significance of Schmidt-type reflectors for the Observatory's researches was emphasized. We are now much nearer to the realization of our dream of having powerful instruments of this new type in both the northern and the southern hemispheres, to strengthen our work in many fields. Especially in the study of external galaxies, faint variable stars, the distribution of Milky Way stars, and the setting up of photometric standards, these rapid wide-field reflectors will be important additions to our equipment.

During the past year steady progress has been made on the mirror and correcting plate for the transformation of our southern reflector to the Schmidt type. The 60-inch spherical mirror has been essentially completed, and now the 60-inch correcting plate is in process of being ground and figured. The question arises as to whether we should send these valuable optical parts to our South African sta-

tion when they have been completed in the shop of J. W. Fecker in Pittsburgh; or should we use this new mirror and this large correcting plate on our 61-inch Wyeth reflector at Oak Ridge? The dimensions of the two reflectors are so nearly alike that without much trouble or expense the new equipment could be adapted, at least temporarily, to the northern instrument. The decision will probably be made during the coming year and depends entirely on the progress of the European war.

But to many of the astronomers at the Cambridge headquarters, the high point in the past year's developments has been the gift to the Observatory by Professor James R. Jewett, of the Observatory's Visiting Committee, of a fund sufficient to finance the completion of a Schmidt-type reflector for the Oak Ridge Station. As the Report year closes, the mounting is eighty per cent completed, both the 33-inch spherical mirror and the 24-inch correcting plate have been completed by the Perkin-Elmer Corporation and delivered to Oak Ridge, and the building also has been finished. The structure that will contain this new reflector is unique in one respect — the whole building rotates on a concrete base. The mounting is of the two-pier type, and has been built in our own Observatory shop by Herbert Hanson, chief mechanic, and his aides. The construction of the mounting and building has been under the supervision of Dr. George Z. Dimitroff, superintendent of the Oak Ridge Station. The new reflector will very appropriately be called the Jewett Memorial Telescope, to commemorate the long and faithful interest in Observatory affairs by Professor Jewett and his wife, the late Margaret Weyerhauser Jewett.

There have been few changes in the personnel of the Observatory during the past year. Dr. Martin Schwarzschild, who was at the Observatory for three years as the Lucius N. Littauer Research Fellow, has been appointed Instructor in Columbia University and began his work in New York in September, 1940. Mr. Dana Bailey and Mr. William Petrie have joined the staff as half-time assistants, with special responsibilities for observing at Oak Ridge.

Miss Ida E. Woods and Miss Florence Cushman, both of whom had retired from their long association with the Observatory, died during the course of the past year. Miss Woods had worked in various departments of the Observatory but will be best known for her discovery on photographic plates of several novae and hundreds of new variable stars. Miss Cushman, who had been on the staff

for forty-nine years, assisted in the administrative work and also in the discussion of the observations submitted by members of the American Association of Variable Star Observers.

During the past summer the Harvard Observatory again held an astronomical conference, attended by many astronomers and astronomical students for a session of six weeks. Dr. Dirk Brouwer of Yale University was the principal lecturer and seminar leader from outside the Observatory staff.

Members of the Visiting Committee and other friends of the Observatory have very generously assisted with emergency needs; and we have obtained grants from various societies and foundations in aid of our many research problems. The Milton Bureau and the Galactic Bureau have continued throughout the year fully staffed and effectively working on the general survey of bright variable stars, and on the survey of the Metagalaxy with the aid of long-exposure plates from Oak Ridge and the Boyden Station. Both of these bureaus are only temporarily financed, and at the end of the next year the Milton Bureau will need to be disbanded unless new provision is made.

If it were not for the unsettled conditions politically and economically throughout the world, we should inquire if this is not the appropriate time to establish by endowment a large computing bureau in the Harvard Observatory. Our great collection of plates, and the numerous available telescopes in the south and north, which are used to enrich the collection in any desired direction, practically demand an agile-minded staff and a large corps of routine workers.

Measurers and computers are needed not only for work on the bright variable stars and for the survey of the galaxies, but also for the systematic classification of faint spectra; for the analysis of Milky Way structure through star counts and color determinations; for the measuring of large numbers of radial velocities of stars; for the studies of positions and proper motions; and for the detailed analyses of the variations of faint stars in galaxies, globular clusters, and our own Milky Way clouds. Much work in these fields has been carried on at the Observatory during the past ten years, but most of it has been on the basis of hand-to-mouth financing, and the use of part-time students from Harvard and Radcliffe.

During the next year some practical steps may be taken to outline the possibility of a general computing bureau here at the Observatory. It may be that work on the plan need not be indefinitely

postponed. Certainly without such an approach we are neglecting the great opportunity that is ours for increasing astronomical knowledge.

During the past year seventy-eight articles have been published by members of the staff, most of which have appeared in the *Annals*, *Bulletins*, *Circulars*, and *Reprints* of the Harvard Observatory. More than half were published in the last named series — that is, first in journals outside the Observatory, this arrangement being necessary because of our diminished budget for Observatory publications. To be sure, some of the papers so published have been more appropriate for outside journals than for Observatory publications, and it now seems advisable to publish systematically certain types of articles in the *Astrophysical Journal*, or in the *Proceedings of the National Academy of Sciences*. A closer affiliation with the *Astrophysical Journal* is under consideration.

HARLOW SHAPLEY, *Director*

NINETY-SIXTH

ANNUAL REPORT

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HARVARD COLLEGE

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Observatory

To the President of the University:

Sir, — During the past year the Observatory suffered a heavy loss through the death of Miss Annie Jump Cannon. In her seventy-seventh year Miss Cannon was still engaged in classifying the spectra of the stars, work in which she was a pioneer and which she had carried on for more than forty years. During that interval the spectra of about half a million stars passed under her scrutiny. In addition to the results published in the Henry Draper Catalogue and the Henry Draper Extension, she had classified approximately one hundred thousand stars, unpublished at the time of her death.

To commemorate the life and work of this gentlewoman, whose kindly advice, enthusiasm, and perseverance charmed and encouraged all who met her, the Observatory has planned a series of memorials. A memorial volume of the Annals, to contain the one hundred thousand unpublished spectra, will soon be issued. The expense of this volume has already been met through the generosity of her friend Professor James R. Jewett, *Emeritus* Professor of Arabic in Harvard University. Two endowed fellowships in the Observatory are contemplated as a further memorial; they would continue to offer the inspiration of Miss Cannon's example to young men and women interested in undertaking the career of astronomical research. One would be available to students from Wellesley College, Miss Cannon's Alma Mater, and would be awarded with a preference to students from Delaware, her native state. The office in which Miss Cannon worked has been set aside as a Memorial Room and will soon be redecorated in an appropriate manner. The type of work that she did will be carried on in this room and in the others that she used. For the continuation of the classification and study of spectra, we have planned a Bureau of Spectral Classification and Milky Way Analysis.

The present international emergency has resulted in several staff changes during the past year. Dr. Theodore E. Sterne, First Lieutenant, United States Army Reserve, left Cambridge in February to join the field artillery at Fort Bragg. During the summer he was transferred for research in ballistics at Aberdeen, Maryland. Mr. Herbert Hanson, chief mechanic, left the service of the Observatory

old 15-inch equatorial needs to be supplemented. The Jewett refractor will also be used in connection with the testing of photographic cameras and also for special research work.

In coöperation with the new National Observatory of Mexico the Harvard Observatory has agreed to construct the mounting of a Schmidt-type telescope, duplicating that made for the Oak Ridge Station. The construction of the instrument is well advanced, and it is hoped that it can be in operation when the new Observatory is dedicated in February, 1942. Located near Tonanzintla, in the state of Puebla, at the latitude of 19°, the observatory will operate on certain problems as an affiliate of the Harvard Observatory. The study of certain portions of the Milky Way, not readily observed from Oak Ridge, has already been undertaken by this new institution. A 3-inch Ross-Fecker patrol camera from our equipment has been sent to the new observatory on indefinite loan. Probably some of the plates made with this instrument will be returned to the Harvard Observatory to supplement the sky patrol carried on in Cambridge and at Oak Ridge and Bloemfontein. During the past summer Dr. Bart J. Bok visited Mexico, on the invitation of the Mexican Government, and was able to outline the coöperative investigations in detail and to assist the staff at Tonanzintla in the early stages of the work.

During the past year a small Bureau for Milky Way Research has been founded and put in operation under the direction of Professor Bok. Through it several of the research programs of the Observatory are brought together to provide a better organized attack upon the problems of stellar distribution and galactic structure. The preparation for the publication of Miss Cannon's spectra is carried on by this bureau.

As part of its service to the local community, the Observatory held ten Open Nights for adults and ten additional sessions for school children during the past year. Approximately twenty-five hundred persons visited the Observatory and became somewhat more enlightened about astronomy and astronomers. Four of the Harvard Books on Astronomy, intended for the layman, have been published and others in the series are nearing completion.

This year the Observatory has become more closely allied with the *Astrophysical Journal*; the Director is now one of the three editors, and selected as a collaborating editor is Mrs. Cecilia Payne-Gaposchkin who is also general editor for the Observatory during the leave of absence of Miss Gladys Wickson.

The largest single publication of the Observatory during this year has been Volume 111 of the *Harvard Annals*, a bibliography and history of the variable stars discovered since 1930. This publication is the first large piece of bibliographic work accomplished by Dr. Richard Prager since his arrival in America. Dr. Prager has become one of the National Research Associates and will thus be enabled to continue his important activities in the interest of the history and bibliography of variable stars.

The researches in various astronomical fields by members of the Observatory staff have been numerous and, in general, successful. Space cannot be taken in this brief report to describe these major responsibilities of the Observatory. Although the numerous national science problems that engage a number of the members of the staff, at least for a part of their time, will tend to curtail or slow up the scientific investigations, it is hoped that the chief programs of the Observatory will be maintained throughout the national emergency with inappreciable diminution.

HARLOW SHAPLEY, *Director*

NINETY-SEVENTH

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Observatory

To the President of the University:

Sir, — No one was more surprised than the members of the Observatory's staff to find that the training for and practice of astronomy appeared to have peculiarly fitted us for effective coöperation in the war effort. Eleven distinct types of military research and service now occupy the full time of about twenty-five members of the scientific staff. Some of the assignments are too confidential to be commented upon in this Observatory Report; but the nature of others in which we are engaged is obvious when one recalls that sailors steer by the stars, and that the Observatory has had to build up and use many kinds of lenses and mirrors and practice various photographic techniques in the normal course of astronomical research.

With so many of us involved in the activities of the national emergency, it is natural that the current output of the results of research is diminished. The telescopes at the southern station, however, are operating at normal efficiency. The work at the Oak Ridge Station has fallen off somewhat because of the almost complete disappearance of graduate assistants from the Observatory staff.

Four members of the observing staff of the Boyden Station in Bloemfontein are in the South African Army. One of them, Mr. Vorster, was in Tobruk at the time of its capture by Axis armies and is believed to be a prisoner of war. Three former members of the Cambridge staff, Dr. Sterne, Mr. Cunningham, and Mr. Thomas, are in scientific work at the Army's Aberdeen Proving Ground, while four others, Dr. Kopal, Dr. Hoffleit, Mrs. Shapley, and Mr. Davoran, are engaged in similar work for the Navy. The teaching of special and regular courses in navigation occupies practically the full time of Dr. Bok, Miss Wright, and Mr. Fleischer. Dr. Menzel and Dr. Dimitroff expect soon to receive commissions in the Navy. Dr. Baker and Mr. Nail, together with several associates, are active exclusively in Government research work, as also are Dr. Watson, Miss Swope, and Mrs. Thomas in another field. Miss Jones has a Government position in Washington and both Mr. Petrie and Mr. Foster have been called into war teaching

work in western universities. In one capacity or other practically all of our graduate students are in war work.

The most interesting of the Observatory's activities during the past year was its participation in the Inter-American Astrophysical Congress in Mexico in February. On that occasion the new Astrophysical Observatory at Tonanzintla in the State of Puebla was dedicated. A part of the equipment had been lent from Harvard, and the mounting of the chief instrument, a large Schmidt-type reflector, was made in our shop. Dr. Dimitroff remained in Mexico for some weeks after the conferences to assist in the installation of some of the equipment and the inauguration of the scientific researches. A dozen members of the Harvard Observatory staff attended the Congress, along with a score of other American astronomers, and through praticipation in the scientific discussions contributed to the Good Neighbor policy of friendly coöperation in science. As a part of the dedication ceremonies, a street leading from the center of the village of Tonanzintla to the Observatory Hill was formally named in honor of Miss Annie J. Cannon.

Steady progress can be reported on the memorial volume for Miss Cannon. Mrs. Margaret Mayall is in charge of a group of workers who are bringing together for that volume the unpublished spectral classifications, which are in excess of seventy-five thousand. It is hoped that the volume will be in print as Harvard Annals 112 when the Observatory centennial ceremony is held in May or June 1943.

The University has made a continuation grant from the Milton Fund for the current fiscal year in order to enable us to prepare for publication the extensive observational material on variable stars, which, during the past four years, we have been accumulating as the result of the operation of the Milton Bureau in the Observatory. The results are beginning to appear. Mrs. Gaposchkin's Colver Lectures in Brown University last spring were based on the work of the Milton Bureau; they are to be published in a small volume during the coming year. The first large technical paper based wholly on the work of the Bureau deals with the RV Tauri variables; under the authorship of Dr. and Mrs. Gaposchkin and Miss Brenton it will appear within the next few months as No. 1 of Harvard Annals 113. Other special types of variable stars will also be grouped for analysis and discussion, and within the course of two or three years the large volume should be completed. There will then remain the question of publishing

the two or three million individual observations derived from the Harvard plates in the course of this work on the bright variables. We may leave the observations unpublished, but have them filed accessibly in the Harvard Observatory; or we may put them out on microfilm when sufficient funds become available to cover the expense of tabulating and photographing.

The study of the corona and other solar phenomena by Mr. Roberts at the Climax Station of the Observatory has progressed very well during the year. Dr. Baker and his associates have been able to provide optical accessories that have much enhanced the value of the solar work. Still further improvement in the coronagraph is designed, but our proposed general attack on certain solar problems must be largely put aside for the present.

For a time during this past summer it began to appear probable that the South African station would need to be closed because of difficulties in the shipment of supplies from Europe or America. A season of uncommonly good weather permitted Dr. Paraskévopoulos and his assistants to break all past records in the amount of work accomplished during June and July of 1942. But this activity naturally depleted supplies of photographic plates and photographic materials. Fortunately the impending shutdown was called to the attention of an agency of the British Government. Now there seems to be a high probability that adequate supplies will soon be landed in South Africa and our work on southern stars guaranteed for a few years. Until ocean transport has become safer, we are not attempting to ship back to America all of the photographs made with the southern telescopes.

Dr. Bok and Mrs. Arons have continued throughout the year to act as the agency established at the Harvard Observatory for the transmitting of astronomical publications and other astronomical information among the astronomers of the various countries now at war. The work has been fairly satisfactory, and it is much appreciated in all countries. Recently Dr. Bok has undertaken to provide for distribution, under the auspices of the State Department, a monthly mimeographed summary of astronomical work all over the world. These summaries are distributed not only by our government representatives in the various foreign countries, but also are sent to the many American astronomers who are away from their astronomical libraries and engaged in war work.

Two years ago a dozen members of the staff of the Observatory undertook to write a series of small general books on various fields

of astronomy. Four of the volumes have appeared during the past year. They are "Between the Planets" by Fletcher G. Watson; "The Story of Variable Stars" by Leon Campbell and Luigi Jacchia; "The Milky Way" by Bart J. Bok and Priscilla F. Bok; and "Earth, Moon and Planets" by Fred L. Whipple. Four additional volumes are completed or nearly completed and will probably appear during the course of the next year. The series has had a favorable reception from students of science and the public.

The Observatory has received a few much appreciated gifts during the past year from friends interested in certain phases of its researches bearing on war problems. Notwithstanding the increasing cost of supplies and labor, the budget is in satisfactory condition, largely because of the absorption of some of our salary responsibilities by the Government or its agencies.

HARLOW SHAPLEY, *Director*

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Observatory

To the President of the University:

Sir, — The Observatory's telescopes have made several thousand photographs of sun, stars, nebulae and galaxies during the past year. Photographically we are running at about eighty per cent of normal performance. But in other respects the Observatory's work moves at the slowest tempo of the past two decades. Last year I reported that twenty-five members of the scientific staff were occupied full time in war work. The number has now reached thirty-two, and that means that few are left for research work. Some temporary replacements have been made, and by a special effort the observing staff at Oak Ridge and the organization in Bloemfontein have been kept up sufficiently to maintain various important series of plates. The galaxy surveys continue; the work on high-latitude faint variable stars, as well as the various studies of the Milky Way, which require the steady accumulation of many plates over a number of years, have all been rather faithfully maintained. The sky-patrol in Cambridge, as well as at Oak Ridge and Bloemfontein, and the two-station meteor triangulations have been kept going without interruption.

Two large shipments of plates were sent through to South Africa during the year, and one small shipment of exposed plates was received. The photographic supplies to a small extent have been obtained in England, but chiefly they must go from the Cambridge headquarters at unrevealed times by unknown routes to unspecified South African ports. We are not attempting to get more plates sent home at the present time.

There has been no loss of mail or supplies since the war began. The transit time of the mail is erratic, but eventually it all comes through. Some of the business, including all financial transactions, is done by radiograms, but we must watch the language of our radio messages. The censors would not like a brief and effective message such as "Nova explosion Puppis shoot nightly using whole battery . . ." followed by positional numbers and the word "urgent"; that sounds subversive. But the equivalent "Make systematic observations of bright new star in constellation Puppis near star Zeta using all telescopes" is satisfactory and expensive.

The current South African plates are being piled up in storage await-

ing two events — safe passage home, and the return of the workers who could use them.

At the present time the South African station is operated at practically no greater expense than in preceding years. This circumstance is partly due to the absence of the higher-paid observers, who are serving in the South African Army. The cost-of-living increment, added by Government requirement to the wages of the dozen employees, does not yet amount to as much as twenty per cent.

The month of June, 1943, was perhaps a little above the average in South Africa. All of the ten telescopes were in use. A part of the monthly record is presented below:

Highest maximum temperature	69°.6
Lowest minimum temperature	24°.0
Average mean temperature	47°.5
Number of totally clear days	13
Number of totally clear nights	21
Hours of darkness	346
Hours of clear night sky	274

Telescope	*Number of exposure hours*	*Number of plates*
60-inch Wyeth reflector	41¼	61
24-inch Bruce refractor	119¼	83
13-inch Boyden refractor	68½	55
10-inch Metcalf triplet	145	169
8-inch Bache doublet	151¾	191
8-inch Brashear	125½	153
3-inch Ross-Fecker lens	155¼	97
3-inch Ross-Tessar lens	33½	12
1.5-inch Cooke lens	147¾	100
1.5-inch meteor camera	111¾	137
TOTAL	1099½	1058

The foregoing summary report for a month's work at the Boyden Station suggests the nature of the enterprise that since 1927 has been under the direct supervision of Dr. John S. Paraskevopoulos. Except for one Greek refugee, his observing staff is wholly of South African origin.

The war-time story of the Climax Station of the Harvard Observatory must naturally be postponed until the close of the war. It has been necessary to make enlargement of the building and increase the shop facilities. The changes were made possible by contributions from two friends of the Observatory. The Climax Station, favorably situated high in the

Rocky Mountains, should be an important asset of the Observatory when the war is concluded, for it now seems certain that a new era in solar research will develop rapidly when the devices and inventions inspired by war can be turned to the more aimless and profitable pursuit of science in peacetime.

Notwithstanding the scarcity of research workers in the Observatory, a considerable number of scientific papers have been published. A number of these papers represent investigations that were nearly finished by staff members or students at the time of leaving the Observatory. Those who remained have generously assisted in the completion and publication of the work.

In the series of Harvard Books on Astronomy, the volume by Dr. Leo Goldberg and Dr. Lawrence H. Aller was completed during the year; its title is *Atoms, Stars and Nebulae*. This volume, like the four earlier items in the series, has had a surprisingly good sale. Second printings will be needed within the next year. My volume of the series, *Galaxies*, is in press, and the book *Telescopes and Their Accessories*, by Dr. James G. Baker and Dr. George Z. Dimitroff, will be printed about the first of next year.

During the year thirty-one Announcement Cards have been issued by the Observatory, the official distributing agency for urgent astronomical news for the Western Hemisphere. The war has cut down the number of cometary discoveries somewhat, and seriously diminished the international work of the American Association of Variable Star Observers, which continues to function as an organization associated with the Observatory. But notwithstanding the war and various censorships, telegraphic communications during the year have reported work from Russia, Finland, Germany, Belgium, Switzerland, Roumania, Denmark, and Argentina. Our own telegrams to Europe are sent exclusively through the Observatory at Lund, Sweden.

HARLOW SHAPLEY, *Director*

NINETY-NINTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1944

BY

HARLOW SHAPLEY

CAMBRIDGE, MASSACHUSETTS
PUBLISHED BY THE UNIVERSITY
1945

[*Reprinted from the Report of the President of Harvard College and Reports of Departments, 1943–44*]

Observatory

To the President of the University:

Sir, — I regret to record a disaster at sea — the loss of the S.S. *Robin Goodfellow* with its crew and its cargo of important materials for war industries. Apparently there had been engine trouble before the ship left port, and possibly a subsequent dropping-out of convoy. A relatively small item in the *Robin Goodfellow's* cargo, but large in the eyes of the Harvard Observatory, was a shipment of astronomical photographs on the way to Cambridge from the Observatory station at Bloemfontein, South Africa. The loss was totally unexpected. The insurance rates on trans-Atlantic shipments had dropped to a very low figure, and our shipping advisors in South Africa and in America had assured us of the relatively high safety of shipments by sea. During the past several years we have made shipments once or twice annually from America to South Africa — shipments of photographic plates and of other materials necessary for the operation of the station; we have had very high insurance costs, but no losses whatsoever. For the past two years we had attempted no return shipments from South Africa. Large quantities of photographic negatives are accumulating in our southern storehouse. Only twice have we had to ration our plate-hungry telescopes for a few weeks or months while awaiting the replenishment of raw materials from England or the United States.

In number of photographic plates our loss by the sinking of the *Robin Goodfellow* is something less than 20% of a year's work. Notwithstanding the presumably low risk, we did, nevertheless, deliberately avoid shipping home the plates made with the patrol cameras. Photographs made with the Rockefeller reflector or the Bruce refractor can be replaced; but the essence of the patrol plates is their continuous coverage of the sky throughout the year, and time cannot be replaced.

In looking over recent Annual Reports from the Observatory, one is struck by the failure to finish off jobs as pledged in the reports. This merely reflects our commendable optimism, when in full pursuit of a scientific project, and also the continually increasing drain by war projects on the personnel of the Observatory staff. The investigators are largely absent, and we do not have computers and other assistants to help carry through the routine researches in the Observatory's programs. For example, the Memorial Volume for Miss Annie J. Cannon, although essentially completed, remains unpublished. The

Jewett telescope at Oak Ridge cannot yet be put into regular operation. The discussion of the Milton Bureau's variable stars progresses slowly.

Although much delayed, because its authors are deeply involved in war work, the volume in the series of Harvard Books on Astronomy, entitled *Telescopes and Accessories*, by Dr. George Z. Dimitroff and Dr. James G. Baker, is completed and within a few weeks of publication. The six earlier volumes in the series have continued to find new readers; four of them have required a second printing. An eighth volume in the series, not heretofore announced, will be entitled *The Relativistic Universe*. It will be written by Dr. Philipp Frank and an associate. The preparation of Dr. Menzel's volume on the Sun and solar problems must be postponed until the end of the war.

A text for courses in navigation was completed during the past year by Dr. Bart J. Bok and Miss Frances W. Wright. The volume, with the title of *Basic Marine Navigation*, has been adopted by a large number of colleges and universities for their wartime courses in navigation. One of the important responsibilities of the Department of Astronomy during the past three years has been the giving of heavily attended courses in navigation for both the civilian and navy students in Harvard College.

During the past year, the Wyeth reflector at Oak Ridge has not been used, and there is little likelihood that it will be put into operation again until the return of the observing staff. The same is true of the Jewett reflector, which is of the Schmidt design. It has been tested mechanically and optically, and to the extent that we find it possible, further improvements in the guiding mechanism, the electric drive, and the plate-holder ensemble will be carried on during the coming year. Test photographs by Dr. Bok, with exposures extending up to two hours, demonstrate that the correcting plate, mirror, and mounting are all highly satisfactory. The instrument will be able to add importantly to our studies of nebulae, variable stars, Milky Way structure, and galaxies when regular operations can be resumed. Mr. Ralph Evans, who was formerly operator of some of the telescopes at Oak Ridge, is now involved in other operations; he writes of recent visits to Berlin and other German cities.

The supervision of the observational work at the Oak Ridge station has this year been largely the responsibility of Dr. Bok. The metagalactic surveys with the Metcalf refractor, as well as the systematic patrol of bright stars and bright meteors, and photometric and spectroscopic studies of the Milky Way, have been maintained. The Oak

Ridge grounds suffered only slight damage from this year's hurricane.

The maintenance of the work at the Climax Station of the Observatory, as at Bloemfontein, has met with personnel difficulties. But both Dr. Paraskevopoulos at the southern station, and Dr. Roberts at the Colorado mountain station, have maintained essentially full operation.

Working with nine photographic telescopes, the Boyden station staff made a new monthly record, 1,218 plates, for July, 1944. Only one night of the month was astronomically useless.

The study of solar phenomenon at Climax continues to yield results of exceptional interest, and we are continually reminded of the advisability of carrying through several developments of equipment and technique in the post-war era, in order that from this nearest of the stars we can enrich our knowledge, both of our own earth and of sun-like stars throughout the Milky Way.

During the past year I have published a revision of the distances of thirty of the globular star clusters and a new estimate of the thickness of the star haze surrounding the galactic system. The Gaposchkins have published, or completed for publication, several papers on interesting variable stars. Each month from the Observatory Dr. Bok issues a mimeographed Astronomical News Letter, which is distributed by the Department of State not only to the embassies and legations abroad for European astronomers, but also to something like a hundred American astronomers who are now away from their observatories and libraries. The material in these Astronomical News Letters comes in part from the astronomical literature of all countries, which we get hold of in one way or another, and in part it is prepared by the astronomers themselves in order to summarize for their colleagues the war-time progress in special astronomical fields. The Harvard Announcement Cards, which carry the "spot news" of astronomy, have been issued in considerable number during the year, notwithstanding the absorption of most American scientists in the war. They have reported Kuiper's discovery of an atmosphere of methane and ammonia on Titan, the large satellite of Saturn; Van Biesbroeck's finding of the star of lowest known candle power; Luyten's finding of a pair of white super-dense dwarf stars; and the discovery of comets by observers in Finland and New Zealand. Harvard's contribution to these discoveries has been only in the providing of some photographic material for others to examine, in the checking of the existence or the motion of some of the comets, and in the routine distribution of the astronomical information.

HARLOW SHAPLEY, *Director*

ONE HUNDREDTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1945

BY

HARLOW SHAPLEY

CAMBRIDGE, MASSACHUSETTS
PUBLISHED BY THE UNIVERSITY
1946

[*Reprinted from the Report of the President of Harvard College and Reports of Departments, 1944–45*]

Astronomical Observatory

To the Provost of the University:

Sir, — The most important activity of the Astronomical Observatory during the past year has been the preparation for the resumption of full-scale research and instruction after an interruption of nearly four years by the exigencies of war. Gradually the members of our staff are being demobilized from the military services and from war research projects. The enrolments in the astronomy classes are returning to normal, with less emphasis on navigation and more emphasis on astronomy as a cultural subject. Perhaps the most significant feature in the rehabilitation of astronomy in Harvard is the enrolment of twelve graduate students at the beginning of the academic year in September. One is a girl from the underground of Holland; another is from Belgium; and a Jesuit father has come from Quebec. It may be that we can soon make up for the deficit in personnel caused by the cessation of most of our graduate work in astronomy since 1940.

I have pointed out in earlier Reports that nearly all of the technical staff of the Observatory and of the Department of Astronomy became involved after 1940 in war researches or directly in the armed forces. I am glad to report that several members of the staff made distinguished records as scientists of the Emergency. Dr. Menzel's work during the past few years has qualified him to work and instruct very effectively in a field that we had not heretofore covered satisfactorily — namely, ionospheric problems and their relation to the earth as a planet and the sun as a star. He should be able now even more effectively than before to be a liaison scientist between astrophysics and other special branches of physics. Dr. Bok, Dr. Watson, Miss Swope, and Miss Wright have all played important parts in the problems of navigation, from the invention of new techniques to the writing of standard texts for the guidance of the armed forces. Dr. Whipple's experience with certain radar techniques may have noteworthy value for post-war astronomy. Dr. Dimitroff, whose work as lieutenant commander has been varied and difficult, is now in Japan on a special mission. During the summer he brought back knowledge from Germany of particular interest to the Observatory, in that it helped appreciably in our plans for improved coronagraphic work.

But probably the Observatory's largest contribution during the war

years has been in the field of ballistics. Both for the Army and the Navy the astronomers and computers from the Harvard Observatory have served in this vital mathematical enterprise. At Aberdeen Proving Ground for the Army were Dr. Sterne, Dr. Cunningham, Dr. Hoffleit, and Mr. Thomas; at the Navy's Bureau of Analysis in the Massachusetts Institute of Technology were Dr. Kopal, Dr. Jacchia, Dr. Prager, Miss Brenton, Miss Mayer, Mrs. Shapley, and Mr. Davoran. At these bureaus not only was the immediately necessary work for the Army and Navy carried on but much research into methods.

Dr. Baker through his management of the Observatory Optical Project for the Office of Scientific Research and Development has made an enviable contribution to the optical techniques necessary in modern warfare. Not only has he planned and designed scores of optical and mechanical accessories, but he has personally supervised the work of a large number of optical workers and mechanics. It is probable that astronomy and other sciences will gain a rich peacetime benefit from his wartime developments in the field of photographic optics.

It seems appropriate to record in this Annual Report one unusual sort of wartime service that has been carried on at the Harvard Observatory. It is the bi-weekly Forum on International Problems. At these meetings in the Observatory library, which have been managed for the most part by Dr. and Mrs. Gaposchkin, serious studies have been carried through of the numerous important international problems that face a society that is slowly moving, it is hoped, from the excesses of irritable nationalism to a more tolerant supernationalism. The meetings have been addressed by prominent members of the Harvard and other Faculties, and have been attended by representatives of all sections of the Boston and Cambridge community. The forum has been of special interest and service to the large number of scholars of the community who have come here in the past decade from other countries.

During the whole of the war one station of the Harvard Observatory has been completely devoted to work for the armed forces. It is the solar station at Climax, Colorado. Under the superintendency of Dr. Walter Roberts we have carried on there systematic observations on solar prominences and on the solar corona, making use of our coronagraph and the accessory equipment that has been devised and built up for advancing the study of the solar surface. Daily the reports on the condition of the sun were telegraphed from Colorado to Washington for incorporation with magnetic and ionospheric data in the interest of predicting radio transmission qualities. Our results were considered of

sufficient importance for daily transmission to England, and they were also distributed to commercial airlines. The information that the coronagraph can give us about the solar corona, for predicting conditions in the ionosphere and therefore for predicting the quality of radio transmission of important information to ships and planes, is in an early stage of development. The results have been so satisfactory, however, that we are encouraged to explore the solar-terrestrial relationships with much vigor now that time for research is being returned to us. The Navy and the Air Forces will probably continue to want results from our solar station, and indeed a contract is in force until the end of the current fiscal year through which we are subsidized to provide daily reports on solar phenomena.

It is clear, however, that a better coronagraph can be made, also that other important solar researches must be undertaken at our high altitude station in the Colorado mountains. For instance, we should make detailed analyses of the solar spicules which have been detected by Dr. Roberts and studied as yet in a most preliminary fashion. Realizing the responsibility to develop the practical use of solar observations, we have formulated plans during the past year for a considerable increase in the equipment of the Climax station. If our plans can be carried out (and they are not extremely expensive), we shall have the new and much improved coronagraph. We shall have special filters, and some spectrographic equipment. It is quite possible that this high altitude station at Climax, Colorado, can be set up as a joint enterprise of Harvard and the University of Colorado. If that is done, it is probable that some other research projects, which can best be undertaken at high altitude (11,000 feet) will be incorporated in the program. We are contemplating studies of meteors, of the night sky, of ionospheric phenomena, and jointly with other institutions of certain phenomena of cosmic radiation. If the plan can be carried through as now proposed, the headquarters for the superintendent of the Climax station will be at Boulder, Colorado, in the physics building of the University of Colorado.

The Oak Ridge Station has been operated at about fifty per cent of full efficiency during the past year. The patrols and the 16-inch Metcalf telescope have been in full time operation, but the Wyeth Reflector has remained idle because of absence of staff. The Jewett Schmidt-type reflector has been put into systematic operation and is yielding excellent results. Dr. Bok and Father LeClaire have devoted much time to this instrument, and several important researches in the field of Milky Way astronomy have been inaugurated.

At the Boyden Station in South Africa, Dr. Paraskevopoulos has

been able to maintain a full-scale staff, and the instruments have been working full time during the year. The past summer season (winter in South Africa) has been unusually favorable for observations; in consequence, important advances have been made observationally on some twenty different research programs. There has been no further loss of plates at sea, but we have attempted shipments only from Cambridge to South Africa. Beginning about the first of 1946 we expect to make monthly shipments from South Africa to Cambridge until we have cleared out the storehouses in which the exposed plates have been accumulated during the past four years.

There have been few publications by members of the Observatory staff during the past year, but the work on variable stars (Milton Bureau project) has continued steadily, and soon we shall have much material for publication — more than we can afford to handle with present resources. Dr. Kopal has completed a monograph on the theory of eclipsing binaries, which will appear next year as one of the Harvard Observatory Monograph series. Dr. Bok has continued to get out his monthly Astronomical News Letter which has been distributed not only to the embattled astronomers of America but to the astronomers throughout the United Nations. By this means we have kept the subject fresh in the minds of astronomers, even though they have been absent from their studies and their telescopes. The seven volumes in the Harvard Books on Astronomy have continued to have an unexpectedly good sale. During the year thirty Harvard Announcement Cards have been issued, reporting on comets, novae, variable stars, and other topics.

Mr. D. du Toit of the observing staff at the South African station has discovered two comets during the past year, both of them through careful watching of the plates made with the nine different instruments that are in operation at the South African station.

Immediately ahead of the Observatory are some serious problems. They include the necessity of re-establishing a computing staff, when the income from endowment is smaller than before and the cost of living and working are higher. We also have the problem of the completion of the transformation of the South African reflector, from the standard Newtonian form to the Schmidt-type. Perhaps a more serious instrumental problem is how to make astronomical use of the instrumental developments that have come about through the high-pressure technology of war.

On the human side a deep concern of the staff of the Observatory is the desperate plight of many of our astronomical colleagues in the war

ravaged countries of Europe. We are aware that the coming year will contain grim realities as well as new opportunities for working with the stars.

HARLOW SHAPLEY, *Director*

ONE HUNDRED AND FIRST

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1946

BY

HARLOW SHAPLEY

CAMBRIDGE, MASSACHUSETTS
PUBLISHED BY THE UNIVERSITY
1947

[*Reprinted from the Report of the President of Harvard College and Reports of Departments, 1945–46*]

Observatory

To the Provost of the University:

Sir, — There are both bright spots and adverse conditions to report this year from the Astronomical Observatories and the Department of Astronomy. This brief account will treat the darker aspects in summary fashion, and put the emphasis on important new developments. It would be negligent, however, not to admit that an uneasy shadow overhangs all of our activities, and that we who are in astronomical work are perhaps more than ordinarily sensitive to its existence. I refer to the international political and social situation. It incites questions such as:

Should we plan to construct large new buildings in urban areas in this age of atomic bombs? Should the staff of the Observatory, with its experience and specialized knowledge, help in the creation of international scientific institutions as a part of its contribution to international sanity? Should our experts in ballistics, rocket problems, optics, turn hopefully away from the wartime applications of science? Should we now work out a plan for burying our best photographs, records, and publications in such a way that they might be discovered and utilized in some later millenium when less social stupidity prevails among the higher animals?

These are deep questions and we acknowledge our concern about them. In this report, however, we turn at once to relatively minor and more concrete difficulties. The static situation with respect to endowments and income, and the rising cost of labor and materials, have made necessary severe restrictions in the general operation of the Observatory. A crisis has developed in the housing and labor situation at our South African Station. We must put three or four of the telescopes out of operation for the time being, for by that procedure we can diminish the size of the South African staff and pay those remaining the wages necessary to compete with industry.

The salaries of the junior staff in Cambridge have been in keeping with those paid elsewhere in the University; but they are insufficient in view of the inflation. With our fixed income, which indeed may decrease if the interest rates decrease, there is nothing one can do about this situation except to find new financial resources, or decrease the size of the staff, which is now about as small as it can be to operate our ex-

tensive plant. Both the Bureau for the Study of Galaxies and the Bureau for the Study of Faint Variable Stars have been wiped out. They were in my charge, and I am now left with but one part-time scientific assistant.

On the positive side I mention first the activities and the new plans for the Climax Station of the Harvard Observatory. In order to finance it and operate it most effectively, we have put it under the joint ownership and management of Harvard University and the University of Colorado at Boulder. At the present moment the Station possesses one coronagraph. It is the only coronagraph in the Western Hemisphere. During the war it did noble work in recording for the armed forces the solar activities which can be correlated with ionospheric and magnetic activity in such a way as to provide useful predictions of radio transmission qualities. Work of this sort must be continued in the interests of civilian and military aviation; but such service is merely a by-product of important new studies of the nearest star.

Although at present small, the new High Altitude Observatory will soon be well equipped with a large new coronagraph, a special solar spectrograph, various crystal filters, and other important accessories. A neighboring new site has been obtained (still on the property of the Climax Molybdenum Company), which will make this highest of astronomical observatories still more efficient in those special astronomical enterprises that can best be carried on above the denser and dirtier part of our atmosphere.

We plan to erect some solar and stellar instruments eventually at Boulder, Colorado, in or near the university; and the graduate schools of both Colorado and Harvard will work in collaboration with our staff at Climax. The superintendent, Dr. Walter O. Roberts, joins Dr. Menzel and me in an Operations Committee for building up the new station and planning its programs.

Associated with the Climax Station will be our new project on the photographic study of meteors. This new undertaking is one of the most significant enterprises of the Observatory of the past decade. It will be under the general supervision of Dr. Fred L. Whipple. For the program we shall build four large meteor cameras of special design, and locate them in the high Colorado mountains. Two will be on the new site of the Climax Station and two others in Montezuma Canyon twenty-two miles (airline) to the northeast.

The optics of the meteor cameras have been designed by Dr. James G. Baker, newly appointed Associate Professor at the Harvard Observatory. Each will photograph an area of the sky with diameter of some

50 degrees, and with a speed several magnitudes faster than anything we have heretofore used. It is our expectation that in a two year observing program we shall open a new epoch in the understanding of the behavior of shooting stars in the high earth's atmosphere, and at the same time provide highly accurate information about the temperature, density, and drag in the atmosphere at various heights above the earth's surface. This information will be of obvious value to aeronautics, and to experimenters on guided missiles, space ships, and extraterrestrial radar. It is not surprising therefore that substantial support for the meteor work is provided by the Office of Naval Research. Government agencies also support the development of the new coronagraph and the operation of the Climax Station.

Another inter-observatory collaboration has been arranged this year which may be of peculiar significance in the Observatory's continued effort to emphasize the internationality of astronomy and the value of cooperation. The Dunsink Observatory near Dublin, Eire, has been dormant for many years; and the Archbishop's Observatory at Armagh in North Ireland has been, for a decade or so, without effective astronomical equipment for modern astronomical research. Our former associate, Dr. Eric Lindsay, is director of the Observatory at Armagh and has personally continued to collaborate with us in studies of the Milky Way. Through the good fortune of a chance meeting with Prime Minister Eamon de Valera at Shannon Field last March, I was able to initiate the plan which with Dr. Lindsay's valuable assistance has culminated in the provision of a new and powerful telescope to be jointly operated by Dunsink, Armagh, and Harvard. It will be located on Harvard Kopje where we maintain eight other instruments. The new Baker-Schmidt two-mirror reflector will make use of the excellent two-pier mounting of the Bruce refractor. We do not increase the number of telescopes in South Africa, but we transform one from an old-fashioned photographic doublet (which has, to be sure, been the great galaxy hunter of the Southern Hemisphere) into an ultra-modern Schmidt-type instrument. The contract for the new telescope has been let; the funds for the transformation have been provided. Within eighteen months we hope to have this instrument in operation on problems of Milky Way structure, variable stars, bright and dark nebulae, external galaxies, and star colors and spectra — all of which are highly important to the current programs of the Harvard Observatory. The new instrument, of which the effective aperture will be not less than 30 inches, will provide the Harvard Observatory in one-third the time more and better photographs than we were obtaining with the Bruce

refractor. The Bruce lens and tube will be kept intact so that at any time in the future we may restore them to the mounting in order to repeat photographs of proper motion fields.

Another important event that makes this year a significant one in the history of the Harvard Observatory has been the appointment to permanent rank of Dr. Fred L. Whipple and Dr. James G. Baker. Not only our research work gains from the addition of these two acknowledged leaders, but the offerings in our graduate work can be much enriched. The Corporation has also appointed as Research Associates, without stipend, four active astronomers of the community, all of whom have made notable contributions in the Observatory's publications. They are Dr. Philipp Frank of the Departments of Physics and Philosophy in Harvard University, Dr. Fletcher G. Watson of the Graduate School of Education in Harvard; and Dr. Zdenek Kopal and Dr. Luigi Jacchia of the Massachusetts Institute of Technology. All will take part in our research conferences, and in our graduate student colloquia. Dr. Walter O. Roberts and Dr. John W. Evans of the High Altitude Observatory at Climax have also been given appointments as Research Associates in the Harvard Observatory.

In order to facilitate the administrative work and responsibilities in the Observatory, we have requested the Corporation to set up officially an Observatory Council which will be responsible for the scientific policies and programs of the Observatory and its out-of-town stations. The members of the Council are Baker, Bok, Menzel, Mrs. Payne-Gaposchkin, Roberts, Shapley, Whipple. Dr. Menzel has been made Chairman of the Department of Astronomy and Associate Director for solar work. Dr. Bok has been advanced to the rank of full Professor, appointed Associate Director of the Observatory, and is in charge of the Oak Ridge Station.

Foreign students have begun to appear in our Graduate School. Among them are representatives of Holland, Belgium, Quebec, and Egypt. Dr. Felix Cernuschi of Argentina has spent the year at Harvard in astrophysical research. Dr. Stanislaw Piotrowski, variable star expert, is on his way to the Harvard Observatory from Cracow for a year's study; and Dr. Chang Yuin, former president of the Sun Yat-Sen University, will soon be here from China as an Agassiz Research Fellow. Visitors from Russia, Sweden, Mexico, Holland, and France have come to the Observatory for scientific conferences.

The publications of the Observatory during the past year have not been numerous. Dr. Kopal's Harvard Observatory Monograph on Eclipsing Binaries has been issued by the Harvard University Press,

and the series of seven "Harvard Books on Astronomy," published by Blakiston, have been reprinted and are selling extremely well. During the report year forty-seven Harvard Announcement Cards have been issued, reporting the current activities of comets and asteroids, and of the astronomers who work on them.

In the forthcoming year one of our outstanding projects will be the celebration of the Centennial of the Harvard Observatory. Preparations have been under way during the current year. As one feature of the Centennial Year, the American Astronomical Society will meet at the Harvard Observatory for several days at the end of December, at which time four special symposia have been arranged, three of them under the management of members of the Observatory staff. Several foreign astronomers will be in attendance at the Centennial meetings, and several special addresses will be made. The papers presented in the four symposia will be collected into a Harvard Observatory Monograph. Probably also the Lowell Institute Lectures, which members of the staff plan to give in January and February of 1947, will be collected into a volume. The subject matter of these lectures is "The Unsolved Problems of Astronomy," and it is quite likely that the eight Observatory participants in the series will be able to outline work that should inspire and activate the Observatory staff for at least the first quarter of the Observatory's second century.

HARLOW SHAPLEY, *Director*

ONE HUNDRED AND SECOND

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1947

BY

HARLOW SHAPLEY

CAMBRIDGE, MASSACHUSETTS
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Observatory

To the Provost of the University:

Sir,—The Centennial of the Harvard Observatory was celebrated during Christmas week of 1946. The date was a convenient approximation. The first formal Astronomical Department was established at Harvard in 1839, in the Dana House, Harvard Yard. The plan for a research observatory on the present site was developed in 1843, under the inspiration of a great comet that awakened interest all over the world, and especially among the citizens of Boston. The "Great Fifteen-Inch Telescope," as it was called in that decade, was completed and brought to "Summer House Hill" four years later. Observation of the positions of stars had already been initiated. The beginning of observational research on the present site, therefore, was commemorated with our Centennial observances in 1946. It had been a highly profitable century in the development of astronomical knowledge, and Harvard had taken a leading part.

A visit to the Oak Ridge Station, a formal reception in the Director's residence, an Open House throughout the Observatory were parts of the commemoration. But the most important item of the Centennial was the five-day meeting at the Observatory of the American Astronomical Society, and the special programs that were developed. Four symposia were the outstanding feature of the Astronomical Society's meetings. In all of them, Harvard Observatory staff members took active part. The titles were:

Some Unsolved Problems in the Theory of Eclipsing Variables
The Gaseous Envelope of the Earth
Interstellar Matter
Electronic and Computational Devices of Interest to Astronomers

All the papers that were contributed to the symposium programs are being collected into a Centennial Volume, to be published soon as Harvard Observatory Monograph Number 7. A small booklet, descriptive of the Harvard Observatory, was published in time to be distributed to the members of the Astronomical Society as a souvenir of the Observatory's first century.

During the war years, as earlier reports have indicated, the Observatory's High Altitude Station at Climax, Colorado, now operated jointly with the University of Colorado, has proved to be of practical use in

the important project of interpreting the ionosphere. With the help of our coronagraph, which is still the only one in the Western Hemisphere, we have been able to contribute from the station at Climax reports on the intensity of the lower corona, and reports on other solar activity. These data, combined with ionospheric and magnetic measures accumulated elsewhere, have proved to be of considerable importance for both military and civilian aviation. The radiations from the Sun, in ways that are not yet fully understood, so clearly affect conditions in the ionosphere that we may properly say that a star has been linked up directly with the problems of radio communication.

Beginning some two years ago we developed plans for the enlargement of the Climax Station, and put special emphasis on the building of a larger and much more effective coronagraph. We have not made the progress in this direction that we should have liked. The difficulty has been financial. We have been able to secure the necessary funds for the operation of the larger station, and for the building up of its equipment, from design to manufacture and installation; but so far we have been unable to obtain the necessary funds for the construction of the buildings that would house the astronomical instruments and astronomical observers at the Climax Station. The regulations governing the various governmental departments interested in the development of our solar work make it impossible for such agencies to provide funds for the construction of permanent buildings. We still have that problem before us—the raising of funds (something like $200,000) for the building operations—before we can realize our plan of enlarging this exceedingly important solar station at Climax. But while awaiting building funds, we are proceeding steadily and effectively in the design and construction of the new equipment.

A significant new development has come our way because of the success of the Climax Station and in recognition of the skill of the staff members who are associated with it. The Air Materiel Command of the United States Army has asked us to look very seriously into the possibilities of establishing another well-equipped solar observatory near Alamogordo, New Mexico. Currently we are exploring the possibilities, both as to observing conditions in New Mexico and as to observational equipment. During the next year we shall decide whether or not to enlarge in a very extensive way our solar work in the Southwest. We can easily justify the simultaneous operation of both the Climax and the Alamogordo stations. And we are happy to report that the new equipment and the new programs are almost exclusively devoted to what one could well call pure research in solar and stellar astronomy.

There are no restrictions on our selection of problems and on the publication of our results.

New Mexico has another important attraction for the Harvard Observatory at this time. The work on the photography of meteors, mentioned in last year's report, has been transferred from the Climax Station to southern New Mexico. The uncomfortably high altitude at Climax is chiefly responsible for the change; but also climatic conditions seem to be better in the semi-desert country a few hundred miles to the south. But the actual observations of meteors in the Southwest are not yet under way. There have been very serious obstacles in getting the glass necessary for the making of the Super-Schmidt cameras. Only at the end of the Report year have we been able finally to get the National Bureau of Standards to undertake the casting of the necessary glass.

We are proceeding to the construction of four meteor cameras, two to be installed at each of the stations, which will be separated by some twenty miles. While awaiting the manufacture of these special cameras, and the installation of the observatories in New Mexico, much experimental work has been done, not only in the photographing of meteors, but in the study of meteor trails. Also several trucks and trailers have been assembled, from army surplus equipment, and they soon will be transformed into meteor "observatories on wheels." It is hoped that systematic observations, perhaps with temporary cameras, will be in progress in the Southwest in the summer of 1948. The funds for the work on meteors will be supplied by the Bureau of Ordnance of the United States Navy. Again we can report that the work we are undertaking to carry out is a program of pure research in meteors and allied problems.

It is worth noting that through the assistance provided by the government, two of the Observatory's five major programs are given new impetus. The departments of solar and meteor research are in prosperous condition, and the Observatory and science should profit greatly from the new endeavors. But three other major branches of the Observatory's research programs, namely variable stars, Milky Way structure, and the galaxies, are not yet rehabilitated. They suffer from lack of working personnel, and of course from the increased cost of materials and technical assistance.

The major administrative job of the Observatory is, for the next year or two, the development of work in these somewhat depressed areas. With the power of our station in South Africa, and the large number of able graduate students, the Observatory is now better prepared than

ever for the study of the southern Milky Way—rich in variable stars, in structural problems, and in galactic anomalies. We are laying out plans for a concerted attack on The Hub of the galactic system.

At the Oak Ridge Station, progress has been made in the rehabilitation of the Wyeth reflector and its preparation for spectroscopic and photoelectric programs. The mirrors and mounting are in good condition, and during the coming year much effective work can be done with our largest reflector. The other instruments have all been restored to operation; the Jewett Schmidt-type reflector has been extremely busy. It has been aluminized during the year, and the mirror protected from moisture through the installation of an appropriate ventilation system. The sixteen-inch refractor has practically finished the long program on the anti-center faint variable stars; and the twelve-inch Metcalf, equipped with objective prism, has provided materials for special studies in the spectral classifications of stars. The graduate students have played an important part in keeping the instruments in effective operation.

A Quonset hut has been erected at Oak Ridge, and the large reserves of Observatory publications now in Cambridge will be transferred to the country for storage.

The South African station has been operated satisfactorily, in spite of much difficulty with the rising cost of labor and the difficulties with housing. The municipality of Bloemfontein has continued to let our observers occupy some humble living quarters at Mazelspoort, the water-works settlement a mile from the Observatory. But the arrangement is temporary. We must act with all effectiveness possible during the next year to solve the problem of living quarters for our South African staff. The housing has become more important than ever because of the good progress toward the completion of the Baker-Schmidt reflector, which is to be jointly operated on Harvard Kopje by the Dunsink, Armagh, and Harvard observatories. This powerful new instrument, which may be completed and in operation within two years, will require additional observers and therefore more living quarters for observers and visiting astronomers.

While awaiting the Baker-Schmidt reflector, which will occupy its mounting, the Bruce telescope continues to be used as in the past. It is giving special attention to rounding off some particular programs. Of these the most important is the series of plates for Dr. W. J. Luyten of the University of Minnesota, who is working on the proper motions of faint southern stars.

During the year three Bulletins of the Panel on the Orbits of Eclipsing Binaries have been issued and distributed to a limited list of

workers in the field of eclipsing binaries. The Panel operates under the auspices of the International Astronomical Union. The Chairman and Secretary, respectively, are Professor Henry Norris Russell and Dr. Zdeněk Kopal, both of whom are Research Associates of the Harvard Observatory. The activity that has been inaugurated through the Panel has in a sense created a new era in the study of the important double stars whose variations are chiefly produced by mutual eclipses. Dr. Kopal's work on eclipsing binaries has been assisted by the Bureau of Analysis of the Massachusetts Institute of Technology, and by grants from the National Science Fund of the National Academy and from the American Philosophical Society.

The regular publications of the Observatory during the Report year include the following:

Harvard Observatory Monograph, Number 6: An Introduction to the Study of Eclipsing Variables, by Zdenek Kopal, Research Associate
Harvard Annals, Volume 115, Parts 5 to 11; Volume 116, Part I
Harvard Circular Number 450
Harvard Bulletin Number 918
Harvard Reprints, Series I, Numbers 278–298, inclusive; Series II, Numbers 15–19, inclusive
Harvard Announcement Cards, Numbers 778–855, inclusive

The current year has been unusually active in the issuance of Harvard Announcement Cards, reporting on comets, asteroids, peculiar variable stars, and other astronomical phenomena requiring prompt knowledge and action. Again the South African observers have contributed usefully in the discovery and photography of new comets. The systematic prompt preliminary examination of the photographs made with the South African telescopes provide the new discoveries.

Professor Henry Norris Russell, long a useful member of our Visiting Committee, has been appointed a Research Associate in the Observatory for the year 1947–1948. The work of the Department of Astronomy has been strengthened through the appointment as instructor of Dr. Armin J. Deutsch, formerly associated with the Perkins Observatory and Ohio State University. Dr. Walter O. Roberts, superintendent of the High Altitude Observatory at Climax, has been in residence at Cambridge during the first semester of 1947–1948, and has assisted in the teaching program. Dr. James G. Baker is on leave of absence. Among the advanced students in the Department of Astronomy is Dr. H. K. Sen of the Department of Mathematics of the University of Allahabad, India. Dr. Chang Yuin of Canton, and Dr. S. Piotrowski of Cracow, have continued in residence as Agassiz Research Fellows.

There are now more graduate students in astronomy than at any time in the past, a situation which correlates satisfactorily with the existence of many unfilled positions in observatories and astronomical departments throughout the country.

HARLOW SHAPLEY, *Director*

ONE HUNDRED AND THIRD

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1948

BY

HARLOW SHAPLEY

CAMBRIDGE, MASSACHUSETTS
PUBLISHED BY THE UNIVERSITY
1949

[*Reprinted from the Report of the President of Harvard College and Reports of Departments, 1947–48*]

Observatory

To the Provost of the University:

Sir, — The first year of the second century of the Harvard College Observatory is not marked by any outstanding discovery by a member of the staff. Steady progress with the new developments of the Observatory, most of which were reported last year, seems to be our best accomplishment. History may record, however, that some of our numerous scientific contributions are more significant than we now recognize. Among them I might mention that Dr. Menzel has ventured an ingenious hypothesis to account for the origin of cosmic rays; Dr. Whipple has extended his theoretical considerations of the origin of the planetary system; Mr. Joost de Jonge, a graduate student, has developed a new technique for the interpretation of stellar motions; much has been done with variable stars, both in our Galaxy and in the Clouds of Magellan.

Our publications merit first attention. To start with the smallest — the Harvard Announcement Cards — there have been an unusual number issued during the report year — No. 847 through No. 940. Cometary observations and calculations dominate the subject matter on these Cards, but they also carry, for instance, news of the discovery of the fifth satellite of Uranus by Dr. G. P. Kuiper at the McDonald Observatory in Texas. It is a new moon that is tiny compared with Texas. Its belated discovery is due to its small size and its nearness to the planet. We had nothing to do with the object, except as official announcing agent. But a supernova in a spiral galaxy, discovered by N. U. Mayall at the Lick Observatory, could be checked up on the Harvard plates, with the result that the pre-explosion history of the object was quickly traced. In spite of the high cost of operation, the various plate series are being maintained in the north and the south, and as a result we frequently produce data of critical importance on swiftly moving comets or asteroids, or on catastrophic bursts of radiation. The Announcement Cards also carried this year notice of the identification by Dr. W. J. Luyten of the hundredth white dwarf star. The discovery of the large proper motions for 61 of these stars, which has led to their identification as white dwarfs in the solar neighborhood, is based on Harvard plates made mostly with our Bruce refractor in South Africa and shipped to the University of Minnesota for examination and measurement.

The other regular publications of the Harvard Observatory appeared as follows:

Harvard Observatory Monograph No. 7, Centennial Symposia
Harvard Annals, Volume 109, Number 11
Harvard Reprints, Series I, Numbers 299–309, inclusive; Series II, Numbers 20–22, inclusive

The Centennial volume contains twenty-four papers presented at our hundredth birthday party at Christmas time 1946. The Harvard Circulars are now taken over for reporting the work of the Panel on Eclipsing Binaries, which this past summer became Commission No. 42 of the International Astronomical Union. The first of this new series, Circular 451, will soon be issued.

Many technical reports have been prepared by various members of the staff during this past year, some in connection with Government contracts (Roberts, Whipple, Menzel), some dealing with science in UNESCO (Bok), and many dealing with the work of the Commissions of the International Astronomical Union. Dr. Menzel has issued (through Prentice-Hall) a technical volume entitled "Manual of Radio Propagation" and has completed the manuscript of his book "Our Sun," which is to be the seventh volume in the Blakiston series of Harvard Books on Astronomy.

The ending of an epoch in the Observatory is signalized by the completion of Harvard Annals 112. It will be in print early next year. This large volume completes the contributions of Dr. Annie J. Cannon. Mrs. M. W. Mayall, who had been Miss Cannon's assistant for many years, has prepared for printing tens of thousands of spectrum classifications which remained unpublished at the time of Miss Cannon's death in 1941. Miss Cannon's famous work at Harvard began in 1896 with the study of the spectra of bright stars in the constellation Carina. Forty-five years later, a month before her death, she was classifying faint stars in that same constellation, bringing her total number of classifications up to the four hundred thousand mark.

Turning to the out-of-Cambridge activities, I first record that the two-station meteor expedition to southern New Mexico under Dr. Whipple's direction is now in operation, although the equipment of cameras is still provisional. Separated by an air distance of about seventeen miles, the Soledad and the Doña Ana Stations, in the valley of the Rio Grande, not far north of the Mexican border, are each operating three cameras, all equipped with rotating shutters. The super-Schmidt meteor cameras, which should greatly improve the work by

getting to the fainter and higher meteors, will require at least another year for construction.

The testing of sites for a large coronagraph installation has been continued this year, with special attention to a location east of Alamogordo, New Mexico, on Sacramento Peak, at an altitude of 9,200 feet. Meanwhile systematic observations of the sun continue on the original site at Climax, Colorado. At our western headquarters in Boulder, Colorado, we proceed with the design of new solar equipment. The staff has been considerably reorganized during the year, with Mr. Robert Carlson as business manager and Dr. C. S. Yü, of Nanking, China, assisting with telescopic design and testing. The transfer of our coronagraph to the new site at Climax was not made this year because of the impossibility of getting housing for instruments and observers.

There have been no instrumental changes at Oak Ridge, except that the Clark 24-inch reflector has been dismantled and the mounting used for the testing of solar instruments. A modern photoelectric photometer and a new short dispersion spectrograph are in operation on the 61-inch Wyeth Reflector, with encouraging results. The spectrographic work is in the hands of Dr. Armin Deutsch, and the photoelectric photometers, built by Mr. A. L. Linnell, are used by him and Mr. Ivan King, a Junior Fellow.

The Oak Ridge Station still needs space for storage, and some road repairing, but otherwise is in good shape and its ten telescopes are efficiently operated on many research programs under the general supervision of Dr. Bok. The Jewett Schmidt-type instrument is particularly effective on galaxies, variable stars, and Milky Way structure. It will soon be working on faint spectra, using the 24-inch prism which has been refigured as a gift of the Perkin-Elmer Corporation.

The South African station continues to be the pride and worry of the Observatory. The staff is intact, and most of the ten instruments are in satisfactory operation, but housing for the observers is still a serious problem. Dr. Paraskevopoulos, the superintendent, is preparing the mounting and the building of the 24-inch Bruce refractor to accommodate, a year from now, the Baker-Schmidt reflector. Within a year we may have also a new two-prism spectrograph working on the Rockefeller 60-inch reflector, as well as a photoelectric photometer. We shall be able to provide suitable observers from Cambridge. But the bogie of housing still remains.

Dr. Bok is actively assisting me in the program of financing our southern station. The development program includes the reestablishment in Cambridge of the bureaus for the study of southern variable

stars, galaxies, and Milky Way structure. The rising cost of basic operations during the past five years had eliminated our technical assistance. Something like forty thousand dollars a year for five years is the amount we should have to put in operation our large joint research on "The Hub of the Universe."

Among the contributions to the Observatory's power during the past year should be mentioned the four grants, averaging over two thousand dollars each, from the Office of Naval Research. Much good scientific work will come out of these contributions. Dr. S. I. Gaposchkin and Dr. C. P. Gaposchkin were assisted by their grant in the initiation of variable star researches at the Mount Wilson Observatory, and their continuation here in Cambridge. Dr. Armin J. Deutsch has been enabled to take up a special spectroscopic research at our Oak Ridge Station and continues next summer with the same problem at Mount Wilson. Dr. Dorrit Hoffleit is assisted, in the analysis of data on stellar distances, through the rental of IBM computing equipment. Dr. Miriam Walther is supported in her work on star spectra, now a joint research project with Wellesley College.

Nine members of the Observatory staff attended the meeting of the International Astronomical Union in Zurich, Switzerland, in August. Of the nearly forty international commissions created by the Union, four have Harvard Observatory chairmen (Kopal, Menzel, Shapley, Whipple) and Mrs. Gaposchkin is chairman of a sub-committee. More than fifty commission memberships were assigned to twenty members of the Harvard Observatory staff by the International Union — a recognition of our wide activity in astronomical work and our practical concern with international cooperation. There is further recognition in the appointment of Dr. Bok as chairman of the National Research Council's Committee on UNESCO, and my membership in the National Commission of UNESCO and in several national and international committees and organizations that have to do with scientific research and administration.

Harlow Shapley, *Director*

ONE HUNDRED AND FOURTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1949

BY

HARLOW SHAPLEY

CAMBRIDGE, MASSACHUSETTS
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[*Reprinted from the Report of the President of Harvard College and Reports of Departments, 1948–49*]

STEWA... OBSERVATORY ... TUCSON

Observatory

To the Provost of the University:

Sir, — Professor Edward C. Pickering, former director of the Observatory, many times emphasized in his Annual Report and elsewhere that both the heart and the goal of the Astronomical Observatory lie in its publications. Indeed his monument at Harvard could well be taken as the four score quarto volumes that were issued as Harvard Observatory Annals under his direction. In a sense the publication of scientific results by the Observatory staff is still the first aim of the Observatory, with the training of advanced students a close second. Admitting this high priority for the publication of our original work, we should expect that there would be ample budgetary provision for the printing. Unfortunately that is not the situation. The Sturgis and Quincy Funds were once adequate. But now the printing costs per page are more than doubled, and the number of contributors within the Observatory has trebled. In addition to the Annals, the Observatory's scientific researches are published in the Circulars, Bulletins, Reprints, and an occasional monographic volume. It has been necessary to discourage full publication. The sending of much of our work to scientific journals outside the Observatory, making special distribution through the issuance of reprints, has not solved our problem. Planographing of tables has helped a little; and the printing of the thousands of observations, contributed yearly by our widespread associates of the American Association of Variable Star Observers, will cost less from now on since we shall issue the work as quarterly reports in mimeograph form.

Publication costs and publication policies are serious problems throughout all the sciences and in most scientific institutions at the present time. Entirely new practices in reporting scientific work may be required to protect both our scientists and our budgets.

The *Oak Ridge Station* of the Observatory continues to be an active institution, where teaching and research are done side by side. Dr. Bok, Dr. Deutsch, and Miss Wright have been the principal staff members who have participated in the night observing at the station, with Mr. Henry A. Sawyer as the only regular astrophotographer. Most of the observing with the station's two largest telescopes, the 61-inch Wyeth Reflector and the 24-33-inch Jewett-Schmidt telescope, has been

done by graduate students and undergraduates concentrating in astronomy at Harvard and Radcliffe. During October of this year, for example, the names of sixteen students appeared on the observing schedule; and in the past summer twenty-five students and guests spent all or part of their time at the Oak Ridge Station, fifteen of them actually in residence. In charge of these student activities was Mr. Arthur A. Hoag, a senior graduate student.

The Wyeth Reflector has been operated with the Stone spectrograph and the new photoelectric photometer; the latter has also been used with an 8-inch Ross camera. The one unused telescope at Oak Ridge, the 24-inch Clark reflector, will go back into operation in the winter of 1949-50. With an aluminized mirror, it will probably be used entirely with a photoelectric photometer, thus leaving the larger reflector almost wholly free for spectrographic work.

In the course of the year three new or refigured objective prisms have become available. The largest is the 24-inch prism refigured through the generosity of the Perkin-Elmer Corporation, and the others are 16-inch and 13-inch prisms made by Mr. Chester Cook of the Observatory staff.

A dozen different research programs are based on the photographic work at the Oak Ridge Station. The collaboration with the Kapteyn Astronomical Laboratory in Holland is continued, our part being the photographing of northern Selected Areas for the determination of standard magnitudes. The past summer was enlivened considerably by the wholly accidental joint discovery of a faint comet by the trio Bappu-Bok-Newkirk, the first a graduate student from Hyderabad, the second the Associate Director of the Observatory, and the third a senior concentrating in astronomy at Harvard.

At the *South African Station* no significant changes in plant or staff have been made, aside from the alterations made in the Bruce refractor building by Dr. Paraskevopoulos and his assistants, in preparation for the transfer to South Africa of the Baker-Schmidt reflector, which is now well along in the last stages of construction by the Perkin-Elmer Corporation in Connecticut. With ten instruments, 4,696 plates were made this year for transfer to Cambridge. The station continues to have serious difficulties with respect to housing for its assistants. As a temporary visitor from headquarters, Mr. Ivan King arrived at the South African Station in July, 1949, where he is engaged in photoelectric photometry, using the 60-inch Rockefeller Reflector and occasionally an 8-inch camera.

The devaluation of the English and South African pound in the fall

of 1949 has immediately brought up special problems, including further increases in the cost of living.

From *Las Cruces*. In summarizing the year's work, Dr. Whipple notes that the newly established meteor stations near Las Cruces, New Mexico, existed rather precariously for their first six months, in a continuous battle against perverse forces, such as electronic control circuits, rocky roads, extraordinarily bad weather, and rattlesnakes. By May, however, Mr. Richard McCrosky and his aides succeeded in overcoming their struggle against Nature. Since then the stations have been operating with high efficiency and the doubly photographed meteors have been increasing our information concerning the nature of these objects and the ballistics of the upper atmosphere. Our meteor project is supported by the Bureau of Ordnance, U. S. Navy.

The long awaited super-Schmidt cameras have been completely designed, and ordered, from the Perkin-Elmer Corporation. The optical glass department of the National Bureau of Standards is collaborating and providing the very difficult glass blanks: Mr. Hahner of that organization has installed a new annealing oven and during the past August successfully molded the first of the part-hemispherical glass shells. Until recently the molding of these shells has constituted the greatest deterrent to the completion of the cameras but the annealing now appears to be a solved problem. We hope that a pair of super-Schmidt meteor cameras will begin action at the New Mexico observing stations during the winter of 1949–50. An incidental operation involves the molding of the photographic film to a curvature comparable to that of soup plates. This project is being attacked by the meteor investigators, particularly Mr. Philip Carroll. There seems to be every hope that relatively simple equipment can transform the flat film into the proper curvature for use with the super-Schmidt cameras.

The work at the *Climax Solar Station*, on both the old and the new sites, is under the direct supervision of our western headquarters at Boulder, Colorado, as is also the work of the exploratory station on Sacramento Peak in New Mexico. The staff at Boulder has been much strengthened during the year, especially for the purpose of developing and designing the coronagraphs, birefringent filters, and other apparatus for solar research. Dr. Walter O. Roberts and Dr. John W. Evans, as superintendent and assistant superintendent, have been assisted administratively by Robert F. Carlson, formerly of the Harvard School of Business Administration, by Will Estlow, and by Dr. J. H. Rush, physicist. Dr. Yngve Öhman of Stockholm has spent the year at Boul-

der, working on problems of polarization; and Dr. C. S. Yü of Nanking has continued to assist with mechanical designs.

We have made some progress toward moving the Climax Station, which is jointly operated by Harvard and the University of Colorado, from its original site to a new location some three miles distant. During the past summer three prefabricated houses (two of the Quonset type) have been erected on the new site; power, water, and sewage systems have been installed, and the road improved up from the highway. Soon a small patrol coronagraph will be installed and operated simultaneously with the existing instrument. A new and much more powerful coronagraph has been designed and will be put under construction within a few months. The problem of providing a building to house this large instrument has not yet been solved.

At *Sacramento Peak* a small coronagraph has recently been installed. Preliminary results confirm our earlier estimate that the New Mexico site is excellent for solar and stellar work. The problem of developing the site further is now being carefully studied. Sky meters and a pole star recorder are in systematic operation.

At the *Cambridge Headquarters* of the Observatory no significant changes in staff, programs, or personnel have occurred, except the addition of Dr. Edith M. Janssen to the group working on solar problems. In order that the widely scattered staff at the six out-stations and in Cambridge may keep in better touch with each other, a mimeographed "House Organ" has been successfully tried out during the past summer.

The regular publications of the Observatory include more than fifty titles, which are listed in the appendix to this report. The nature of the current researches, which we do not have space to describe in the Annual Report, can be inferred from the bibliography. It should be noted that some of the contributions are by visitors to the Observatory, some by graduate students, and some by our research associates, Drs. Russell, Kopal, and Jacchia. Two important volumes are in the list — the Annie J. Cannon Memorial by Miss Cannon and Mrs. Mayall, and Menzel's "The Sun", the seventh of the Harvard Books on Astronomy.

The undergraduate curriculum and enrolments showed no significant changes from previous years. The Director gave a new summer course — Introduction to Cosmogony. For the benefit of staff and advanced students numerous colloquia and Hollow Square Conferences were held, and for the public two series of Open Nights.

Attending scientific meetings in Europe, in August, were Dr. C. P.

Gaposchkin and Dr. Shapley; visiting and working at California observatories during the summer were Dr. Deutsch, Mr. and Mrs. Federer, Dr. Hoffleit, and Dr. S. Gaposchkin, and a dozen from the Observatory took part in the American Astronomical Society's annual meeting in Ottawa.

HARLOW SHAPLEY, *Director*

Appendix to the Report on the Harvard College Observatory

Publications for the Year 1948–1949

The following publications have been issued during the year by the Observatory.

Annals:

Vol. 112. The Annie J. Cannon Memorial Volume of the Henry Draper Extension. By Annie J. Cannon and Margaret W. Mayall.

Vol. 116, Nos. 2, 3, and 4. Variable Star Observations. By Leon Campbell.

Vol. 120, No. 1. Solar Prominence Distribution during 1942–1945. By Lewis Larmore.

Circulars: On Close Binary Systems.

No. 451. Introduction. By Z. Kopal.
Present Needs in the Study of Eclipsing Binaries. By H. N. Russell.
The Construction and Use of a Photomultiplier Type of Photoelectric Photometer. By G. E. Kron.
A Commercially Available Amplifier Type Photoelectric Photometer. By H. T. Sterling.

No. 452. The Penumbral Part of the Reflection Effect in Eclipsing Variables. By H. N. Russell.
RY Scuti. By D. J. K. O'Connell, S.J.

No. 453. The Monochromatic Coefficients of Darkening for the Main Sequence Stars. By G. Münch and S. Chandrasekhar.

No. 454. Detailed Effect of Limb Darkening upon Light and Velocity Curves of Close Binary Systems. By Z. Kopal.

Bulletins:

No. 919. Papers on variable stars, clusters, and galaxies by B. Bell, B. J. Bok, S. Gaposchkin, D. Hoffleit, I. King, M. W. Mayall, V. McK. Nail, M. Olmsted, and H. Shapley.

Announcement Cards:

Nos. 941–1038. Reports on comets, novae, asteroids, variable stars, etc.

Reprints:

Nos. 310–321 and Series II, Nos. 23–31. Miscellaneous papers, most of which are listed below.

BOK, B.

UNESCO: A Work in Progress. Physics Today, Vol. 2, no. 7.

The Milky Way at the Junction of Gemini, Monoceros, and Orion. With M. Olmsted, and B. D. Boutelle. Astrophysical Journal, Vol. 110, no. 1.

Freedom of Science and the Declaration of Human Rights. Bulletin of the Atomic Scientists, Vol. 5, no. 8–9.

CAMPBELL, L.

Nine Variable Star Notes. Popular Astronomy, Vol. 56.

CHANG, Y.

Changes in the Period and Light Curve of the Cluster-Type Variable SX Ursae Majoris. Astronomical Journal, Vol. 54, no. 1.

CRAIG, R. A.

Vertical Eddy Transfer of Heat and Water Vapor in Stable Air. Journal of Meteorology, Vol. 6, no. 2.

DEUTSCH, A. J.

The Sun. Scientific American, Vol. 179, no. 5.

EVANS, J. W.

A Photometer for Measurement of Sky Brightness near the Sun. Journal of the American Optical Society, Vol. 38, no. 12.

The Birefringent Filter. Journal of the American Optical Society, Vol. 39, no. 3.

HOFFLEIT, E. D.

V-2 Rockets in Exploration and Science. Popular Astronomy, Vol. 57, no. 1.

The Quest for Stellar Parallax. Popular Astronomy, Vol. 57, no. 6.

DOVAP — A Method for Surveying High-Altitude Trajectories. The Scientific Monthly, Vol. 68, no. 3.

JACCHIA, L. G.

Ballistics of the Upper Atmosphere. Technical Report No. 2. NOrd Tasks D & I for Bureau of Ordnance of U. S. Navy Department.

Photographic Meteor Phenomena and Theory. Technical Report No. 3. NOrd Tasks D & I for Bureau of Ordnance of U. S. Navy Department.

KIEWIET DE JONGE, J. H.

On the Relationships between the Frequency Functions of Stellar Velocities. Proceedings of the National Academy of Sciences, Vol. 34, no. 12.

KOPAL, Z.

Remarks on the Determination of Intermediary Orbits of Eclipsing Binary Systems. Astrophysical Journal, Vol. 108, no. 1.

Radial Oscillations of the Limiting Models of Polytropic Gas Spheres. Proceedings of the National Academy of Sciences, Vol. 34, no. 8.

Nonradial Oscillations of the Standard Model. Astrophysical Journal, Vol. 109, no. 3.

MENZEL, D. H.

Our Sun. The Harvard Books on Astronomy. The Blakiston Company.

The Origin of Cosmic Rays. With W. W. Salisbury. Nucleonics, Vol. 2, no. 4.

The G Layer of the Ionosphere. With D. K. Bailey. Relations Entre Les Phénomènes Solaires et Géophysiques. Colloques Internationaux de Lyon, 1947.

Transfer of Radiation. With H. K. Sen. Astrophysical Journal, Vol. 110, no. 1.

PIOTROWSKI, S. L.

An Analytical Method for the Determination of the Intermediary Orbit of an Eclipsing Variable. Astrophysical Journal, Vol. 108, no. 1.

A Study of the Orbit of Beta Aurigae. Astrophysical Journal, Vol. 108, no. 3,

ROBERTS, W. O.

Association of Corona with Prominences. Astrophysical Journal, Vol. 108, no. 3.

RUSSELL, H. N.

Preliminary Solutions for Eclipsing Binaries from Accurate Observations. Astrophysical Journal, Vol. 108, no. 1.

SHAPLEY, H.

The One World of Stars. Science, Vol. 108, no. 2804.

Time and Change in the Metagalaxy. Scientific Monthly, Vol. 67, no. 4.

Cepheid Variable Stars in the Small Magellanic Cloud. With V. McK. Nail. Proceedings of the American Philosophical Society, Vol. 92, no. 4.

The Standard Cepheid Light Curve. Proceedings of the American Philosophical Society, Vol. 93, no. 1.

A Half Century of Globular Clusters. Popular Astronomy, Vol. 57, no. 5.

The Committee on Inter-American Scientific Publications. Science, Vol. 109, no. 2842.

THOMAS, R. N.

Superthermic Phenomena in Stellar Atmospheres. Astrophysical Journal, Vol. 108, no. 1.

WALTHER, M. E.

Anomalous Spectra of Stars of Class A. Astrophysical Journal, Vol. 110, no. 1.

WHIPPLE, F. L.

Seasonal Variations in the Density of the Upper Atmosphere. With L. G. Jacchia and Z. Kopal. University of Chicago Press, "The Atmospheres of the Earth and Planets."

Harvard Photographic Meteor Program. Sky and Telescope, Vol. 8, no. 4.

The Upper Limit to the Electron Density Near the Earth's Orbit. With J. L. Gossner. Astrophysical Journal, Vol. 109, no. 3.

ONE HUNDRED AND FIFTH

ANNUAL REPORT

OF THE

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THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1950

BY

HARLOW SHAPLEY

CAMBRIDGE, MASSACHUSETTS
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[*Reprinted from the Report of the President of Harvard College and Reports of Departments, 1949–50*]

Observatory

To the Provost of the University:

Sir, — Two important steps have been taken during the year toward enriching the research equipment of the Observatory. Work was begun on the manufacture at the Westinghouse plant in California of two "spars" to carry the large coronagraphic equipment of the western solar stations, discussed below by Dr. Menzel; and the Armagh-Dunsink-Harvard reflector has been delivered to our southern station and is being mounted and tested under the direction of Dr. J. S. Paraskevopoulos and Dr. Bart J. Bok. Both this 33–36-inch Baker-Schmidt reflector and the coronagraphs are unique and powerful instruments. They should play important parts in the future work of the Observatory, one dealing with the sun, eight light-minutes away, and the other with the stars of the Milky Way and with the galaxies, one hundred million light-years distant.

The completion of the new meteor cameras, the transformation of the Rockefeller reflector, the finishing of the big prism for the Armagh-Dunsink-Harvard telescope cannot yet be announced. In these days of rearmament we naturally find the manufacture of research equipment frequently delayed by urgent government projects. But on all three of these important items, notable progress can be recorded.

Many good advances in scientific research, both observational and theoretical, have been made during the year, but following the custom of past years we use our limited space in the Annual Report to give an account chiefly of equipment, personnel changes, and organizational details; the scientific work must be inferred from the bibliographic appendix to the Report.

Although it has been a good year, and the prospects just ahead are appealing (except for the threatening clouds of war), the Observatory is not wholly free of the embarrassment caused by inflation. We continue our stringent economical measures, even to the extent of limiting some of the programs that are expensive in photographic material. The cancellation of the sky patrol has been contemplated, but since no other observatory appears to be carrying on such work systematically, we feel obliged to maintain our sixty-year old practice of systematically photographing the whole sky many times a year in both northern and

southern hemispheres. But the coverage need not be as frequent as in the past. We no longer feel the need of so many plates on the brighter variables. The Milton Bureau survey of the variables brighter than the tenth magnitude has made use of tens of thousands of these patrol plates; its recent completion by Mr. and Mrs. Gaposchkin fulfills one of the original objectives of the steady sky patrol.

Another embarrassment is the difficulty of finding competent observing assistants for the programs at our southern station. We find it difficult to compete with war industries, especially since night work on a lonely kopje has little appeal and we cannot offer seductive wages. The presence this year in South Africa of Dr. Bok and of two of our graduate students, Ivan King and Uco van Wijk, temporarily alleviated the man-power shortage. It may be that we shall operate some of the lesser instruments only on the most favorable nights, concentrating our diminished observing efforts on the work of the new A-D-H telescope, and on the photoelectric photometer and the new spectrograph used in connection with the Rockefeller reflector.

Our large effort in building up the solar stations in the west is summarized by Dr. Menzel:

> During the past year developments at the High Altitude Observatory of Harvard University and the University of Colorado at Climax have seen increased activity at the new site on the north side of Chalk Mountain. A small patrol coronagraph, built with funds provided by the Research Corporation, will soon go into action. The work of this instrument will supplement and ultimately replace that now being done with the pilot instrument at the old site.
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> The design for the large coronagraph has been completed and a contract let for its manufacture to the Westinghouse Company, Sunnyvale, California. The optical design for this instrument is also nearing completion, the necessary large discs have been secured, and plans are under way for initiating the manufacture of the basic optics. One serious problem, for which no immediate solution is in sight, is the housing of the new large coronagraph.
>
> Yale University has joined Harvard University and the University of Chicago in the use of Climax for all-year-round cosmic-ray research. Additional scientific institutions have expressed an interest in the location. The combination of all-year-round accessibility and the availability of electric power make the site particularly desirable for certain types of cosmic-ray research for which success does not depend on operation at the highest of altitudes.
>
> The past year has also seen a considerable development of the Sacramento Peak Station of Harvard Observatory near Alamogordo, New Mexico. A small coronagraph has provided important data concerning the activity of the sun's corona and a second small coronagraph, recently set into operation, takes daily records of the prominence activity. Under development, and intended for early installation at Sacramento Peak, is a special device for the detection of "flares"

on the solar disc. This device, although not yet in its final form, has been in provisional operation at Boulder, Colorado. The records from it of certain types of solar activity have been the most complete as yet available.

The year has witnessed an appreciable expansion in the building at Sacramento Peak. A number of Quonsets have been installed to provide space for offices and housing for observers. The turret and enclosure for the large coronagraph have been started and the concrete work nearly completed. The structure will be ready next spring or early summer.

The construction and research activities at both of these stations are at present coordinated through the headquarters at the High Altitude Observatory at Boulder, Colorado. The Air Materiel Command has furnished funds for the development of Sacramento Peak; the U. S. Navy, funds for the development of the large coronagraph at Climax; the Research Corporation, for the small spars and associated coronagraphs for Climax and Boulder; and the National Bureau of Standards, for the basic operation of the Climax station and reduction of the records. Full coordination of the scientific phases of the work comes from the Harvard Observatory in Cambridge, where numerous problems of the relationship between the sun and the earth are currently under investigation.

Dr. Whipple summarizes the work on meteors in Cambridge and New Mexico as follows:

The Meteor-Ballistic Project carried out under the U. S. Naval Bureau of Ordnance Contract has been very active during the past year. The two observing stations near Las Cruces, New Mexico, have photographed approximately sixty meteors simultaneously from the two stations. All preparations for the installation of the Baker Super-Schmidt meteor cameras at these two stations are now complete. The preliminary experimentation and the final design of the equipment for molding the photographic film for these cameras have been finished. We hope that the Super-Schmidt cameras will be put in operation during the winter of 1950–51. Mr. Peter Cioffi has left the observing staff and Mr. Gunther Schwartz and Mr. Irwin Levitan have joined the observing teams.

Graduate instruction continues to be one of the major responsibilities of the Cambridge staff. We have decided to limit to not more than fifteen the number of advanced students we undertake to guide. The recent growth of other graduate schools of astronomy in America relieves us of some responsibility. We have found that the researches of the major staff members of the Observatory are helped with a few good students, and delayed with too many. At the end of the year, the spring of 1950, seven of our graduate students were given positions in the Naval Observatory (three), University of Michigan (two), University of Pittsburgh (Allegheny Observatory), and Wellesley College. Much systematic observing work at the Oak Ridge station has been carried on by students.

No particular changes have been made in the equipment of the Oak Ridge station or in Cambridge, except that the Agassiz 7½-inch telescope, used in the elementary instruction, has been moved from Jarvis Street to the Observatory grounds. The Jarvis Street buildings had to be removed for the new graduate dormitories, and the Department of Astronomy was transferred during the summer to Byerly Hall, Radcliffe.

Two meetings of the Overseers' Committee to Visit the Observatory have pleasantly demonstrated the deep and sincere interest of these "Visitors" in our programs and our progress. Substantial financial support has come from some members of the Committee, especially in support of the Bok-Shapley investigations of the "Hub of the Universe." Some of the members have helped also in the negotiations with government agencies relative to the work and financing of our solar operations in the West. It might be noted, incidentally, that the total expenditures by the Harvard Observatory for the advance of astronomical science during the Report year have been approximately half a million dollars. Much of this expenditure was, of course, for the development of the solar and meteor instrumentation under government contracts.

During the year the Observatory has received a number of distinguished visitors. At the head of the list should be placed the name of Prime Minister Jawaharlal Nehru, who is directly interested in the scientific development of India, including astronomical observatories. Among others were Dr. Giorgio Abetti of Arcetri, Italy; Dr. Bertil Lindblad of Stockholm; Dr. A. C. Banerji of Allahabad, India; Dr. Carlos Graef of Mexico; Dr. J. G. Bolton of Sydney, Australia; Dr. A. Wallenquist of Upsala, Sweden; Dr. D. Barbier of Paris; Dr. I. S. Bowen and Dr. Walter Baade of Mount Wilson and Palomar; and Dr. Erwin Freundlich of Aberdeen, Scotland. Nearly all of these lectured to our staff and students, and Professor Henry Norris Russell, research associate, spent two weeks with us as general advisor on various programs. Dr. James G. Baker, research associate, has returned from two years in California and now occupies offices in Building A. Dr. George C. McVittie of London is Visiting Lecturer on Cosmogony. Dr. Armin J. Deutsch, lecturer in Astronomy for the past three years, has resigned to accept a position on the staff of the Mount Wilson and Palomar Observatories.

HARLOW SHAPLEY, *Director*

Appendix to the Report on the Observatory

Publications for the Year 1949–1950

A. The following regular publications have been issued during the year by the Observatory.

Annals:

Vol. 88, No. 7. Harlow Shapley, Rebecca B. Jones, Virginia McK. Nail. A Census of Northern Galaxies in an Area of 3600 Square Degrees.

Vol. 115, Nos. 12–27. Cecilia Payne-Gaposchkin and Sergei Gaposchkin. Variable Stars in Milton Fields Nos. 28–43.

Vol. 119, No. 1. Dorrit Hoffleit. The Spectra and Absolute Magnitudes of 500 A3–G2 Stars.

Quarterly Reports:

Nos. 1 and 2, American Association of Variable Star Observers. Margaret W. Mayall, Recorder.

Announcement Cards:

Nos. 1039–1101. Reports on comets, novae, asteroids, variable stars, etc.

Reprints:

Nos. 322–337 and Series II, Nos. 32, 33. Miscellaneous papers, all of which are listed below or in last year's report.

B. The following papers appeared in journals not published by the Observatory.

BOK, B. J.

The Use of the Schmidt Telescope in Stellar Photometry. With M. Olmsted. Popular Astronomy, Vol. 58, no. 6.

The Southern Milky Way. Monthly Notices of the Astronomical Society of South Africa, Vol. 9, no. 6.

CAMPBELL, L.

Variable Star Notes. Popular Astronomy, Vol. 57. (H.R. 327).

CRAIG, R. A.

The Observations and Photochemistry of Atmospheric Ozone and their Meteorological Significance. Meteorological Monographs, Vol. 1, no. 2.

DEUTSCH, A. J.

The Abundance of the Elements. Scientific American, Vol. 183, no. 4.

GAPOSCHKIN, S.

1. Spectroscopic Double Star HD 218066 = BD +62°2163.
2. Eclipsing Variable of the Wolf-Rayet Type HD 168206 = CV Serpentis.
3. Spectroscopic Double Star BD + 40°4115 = Eclipsing Variable V 470 Cygni.
4. Spectroscopic Binaries which are not Eclipsing Variables. All in Variable Stars, Vol. 7, no. 1.

HOFFLEIT, D.

Some Firsts in Astronomical Photography. Booklet issued by the Observatory.

Van Houten's Nova Velorum 1940. Astronomical Journal, Vol. 55, no 5.

Daytime Meteors of August 7, 1869. Popular Astronomy, Vol. 58, no. 8.

Seeing. Sky and Telescope, Vol. 9, nos. 3, 4.

The First Star Photograph. Sky and Telescope, Vol. 9, no. 9.

JACCHIA, L. G.

A Photographic Study of the Draconid Meteor Shower of 1946. With Z. Kopal and P. M. Millman. Astrophysical Journal, Vol. 111, no. 1.

Atmospheric Density Profile and Gradients from Early Parts of Photographic Meteor Trails. Technical Report no. 4. (H.R. Series II–32).

KOPAL, Z.

Radial Oscillations of the Generalized Roche Model. Astrophysical Journal, Vol. 111, no. 2.

MENZEL, D. H.

New Studies of the Sun. With A. J. Deutsch. Research Reviews, ONR.

Astrophysicists Watch the Sun. With C. B. Wyatt. Physics Today, Vol. 3, no. 3. (H.R. Series II–33).

Origin of Sun Spots. Nature, Vol. 166, no. 4209.

The Chemical Composition of Planetary Nebulae. Transactions of the International Astronomical Union, Vol. 7, pp. 468–471.

El Sol y El Universo. El Universo, Vol. 58, no. 4.

The Physical Principles of the Quantum Theory. With D. Layzer. Philosophy of Science, Vol. 16, no. 4. (H.R. 332).

NAIL, V. MC K.

Observations of V 465 Cygni–Nova Cygni 1948. With J. Ashbrook. Astronomical Journal, Vol. 55, no. 3.

ÖHMAN, Y.

The Use of Savart Fringes in the Observation of Zeeman Effects in Sunspots. Astrophysical Journal, Vol. 111, no. 2. (H.R. 334).

PAYNE-GAPOSCHKIN, CECILIA.

Worlds in Collision. Popular Astronomy, Vol. 58, no. 6.

ROBERTS, W. O.

Observations of Chromospheric Opacity. Publications of the Astronomical Society of the Pacific, Vol. 62, no. 368.

SEN, H. K.

The Radiative Equilibrium of a Spherical Planetary Nebula. Astrophysical Journal, Vol. 110, no. 2. (H.R. 329).

SHAPLEY, H.

Galactic and Extragalactic Studies XX. On the Distribution of 78,000 of the Brighter Northern Galaxies. Proceedings of the National Academy of Sciences, Vol. 36, no. 3. (H.R. 333).

Astronomy. Scientific American, Vol. 183, no. 3.

Relative Diameters of Galaxies. Nature, Vol. 166, no. 4213.

Galactic Rotation and Cosmic Seasons. Sky and Telescope, Vol. 9, no. 2.

The Creation of an International Observatory. Transactions of the International Astronomical Union, Vol. 7, pp. 418–419.

THOMAS, R. N.

Superthermic Phenomena in Stellar Atmospheres, III. The Chromospheric Radiation Field. Astrophysical Journal, Vol. 109, no. 3. (H.R. 322). IV. Comment on Regions of Emission Fluctuations in the Solar Atmosphere. Astrophysical Journal, Vol. 112, no. 2.

The Ballistic Contribution to Meteorics. Technical Report no. 5 (H.R. Series II–34).

VAINU BAPPU, M. K.

The Spectrum of the Light of the Night Sky During the Recent Sunspot Maximum. Astrophysical Journal, Vol. 111, no. 1. (H.R. 336).

VAN DIEN, E.

The Stark Effect of the Higher Balmer Lines in Stars of Spectral Types A and B. Astrophysical Journal, Vol. 109, no. 3. (H.R. 323).

WARWICK, C.

The Effect of Irregular Absorption on Galaxy Distribution. Proceedings of the National Academy of Sciences, Vol. 36, no. 8.

WHIPPLE, F. L.

The Polar Axis Adjustment of Photographic Telescopes. Popular Astronomy, Vol. 57, no. 9. (H.R. 326).

A Comet Model, I. The Acceleration of Comet Encke. Astrophysical Journal. Vol. 111, no. 2. (H.R. 337).

Periodic Heat Transfer by Radiation through Layers in a Vacuum. With J. O. Gadd. Computation Laboratory of Harvard University Contribution AT (30–1)–497.

Review of Meteoric Astronomy 1938–1948. Transactions of the International Astronomical Union, Vol. 7, pp. 240–246.

WRIGHT, F. W.

The Photographic Taurid Meteors. With F. L. Whipple. Technical Report no. 6. (H.R. Series II–35).

WYATT, S. P.

The Poynting-Robertson Effect on Meteor Orbits. With F. L. Whipple. Astrophysical Journal, Vol. 111, no. 1. (H.R. 335).

ONE HUNDRED AND SIXTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1951

BY

HARLOW SHAPLEY

CAMBRIDGE, MASSACHUSETTS
PUBLISHED BY THE UNIVERSITY
1952

Observatory

To the Provost of the University:

Sir, — With regret I record the completion of the careers of two of the Observatory's most valued workmen. Mr. Leon Campbell, Pickering Memorial Astronomer, had been associated with the Observatory in various capacities for more than fifty years. The Observatory was his life, and his work was the Observatory's pride. More than anyone else, Mr. Campbell held together and greatly expanded the world-wide association of observers and small observatories that forty years ago had been congregated into the American Association of Variable Star Observers. Although he had retired from responsibility and active work, he continued his analysis of the great accumulation of measures of the light of long-period variable stars. His concluding volume will soon be finished by others and published through the munificence of Dr. Lawrence N. Upjohn, a generous member of the fraternity of variable star observers.

In the death of Dr. John S. Paraskevopoulos, Superintendent of the Boyden Station, the Observatory lost a skilled manager of the affiliate that is remote in a geographical sense but is very close to the heart of the Observatory in scientific research. From 1923, when the Boyden Station was still in Peru, Dr. Paraskevopoulos directed the Station, managed the personnel, and produced the photographic material that has kept the Harvard Observatory a dominant institution in the study of the southern skies. He moved the telescopes to South Africa and installed new ones; he was builder and diplomat, and adept at working with tight budgets.

The death of Dr. Paraskevopoulos created for the Harvard Observatory problems of reorientation and effective replacement; but fortunately Associate Director Bart J. Bok was in South Africa at the time. The transition to a new administration was quickly accomplished and already Dr. Eric M. Lindsay, Director of the Archbishopric Observatory in Armagh, Northern Ireland, has taken over, at least temporarily, the superintendency of our southern station. In a later paragraph Dr. Bok describes the new equipment at the Boyden Station and the current activities.

The program of research and advanced instruction at the Observatory headquarters in Cambridge has prospered during the year. Notwithstanding the inflation, we have been able to keep the budget balanced without too severe restriction on maintenance, on the quality and quantity of supplies, or on the number of assistants. This success is due in

part to careful economies but also to the receipt of additional operating funds from various sources, including gifts from friends of the Observatory, grants from Academies and research committees, and contracts with Government agencies for work in various fields, especially on meteors and the sun.

At the Oak Ridge Station, we have built a small storage house for our stock-pile of Harvard Observatory publications. An 8-inch visual telescope of high quality — the gift of Mr. and Mrs. Walter T. Rosen of Katonah, New York — has been received, and will be mounted in a building already available. It constitutes a memorial to Flying Officer Walter Bigelow Rosen of the Harvard Class of 1937, who died in the second World War.

Dr. Donald H. Menzel, Associate Director for Solar Research, reports as follows on the work at the Colorado and New Mexico Stations and in the solar department here in Cambridge:

As of July 1, 1951, the High Altitude Observatory of Harvard University and the University of Colorado became a separate institution in practical operation; some five years earlier it had already been set up as an independent corporation under the laws of the State of Colorado. Formal responsibility for the management of the High Altitude Observatory rests in the Board of Trustees, four appointed by the President of Harvard University and four by the President of the University of Colorado. These trustees have appointed a Committee on Scientific Operations, whose duty it is to advise the Board of Trustees and to pass on the budget of the High Altitude Observatory. The headquarters remain on the campus in Boulder.

The Upper Air Research Station at Sacramento Peak, N. M., is in the process of marked expansion at the present time. The large turret and spectrograph wings, to provide observing quarters for the new 16-inch coronagraph and accessory equipment, are almost complete. Construction has been started on a number of other buildings, including laboratory and office space, houses, and dormitories for observers, maintenance and administration buildings, etc. In addition, one of the small coronagraphs has been relocated and the other coronagraph greatly improved in its operation. The regular reports of solar activity are transmitted daily by radio to the High Altitude Observatory headquarters in Boulder, Colorado, where a joint report of solar data from the Sacramento Peak and Climax records is made up and sent to Washington. The facilities on Sacramento Peak will be used by Harvard University under

an Air Force contract, and shared directly with Air Force personnel and with personnel from Cornell University, also operating under an Air Force budget.

At present, observing at Sacramento Peak is in the hands of four men, with Mr. Harry Ramsey acting as "observer-in-charge" to replace Mr. Rudolph Cook, who left in June to enter the University of Colorado.

The contracts have been let for the construction by the Westinghouse Company at their plant in Sunnyvale, California, of two 16-inch coronagraphs, one destined for Sacramento Peak and the other ultimately for Climax. Delivery is expected not later than next spring. In the meanwhile, designs for the optical portion of the instruments have been completed and construction started.

The High Altitude Observatory, as part of its research activity, has accepted a contract with the Office of Naval Research for the preparation of special equipment and the operation of that equipment in connection with the forthcoming total solar eclipse of February 25, 1952. Several members of the High Altitude Observatory will observe the eclipse from Khartoum, Sudan, under the supervision of Dr. Walter O. Roberts and Dr. John W. Evans.

During the current year, further progress has been made toward the moving of the coronagraph from its original location at Climax to the new site, a few miles away, on the north slope of Chalk Mountain.

Solar research in Cambridge has been largely along theoretical lines, although one of our graduate students, Mr. Richard B. Dunn, has found a new use for the century-old instrument, the 15-inch refractor. Additional practical work has been carried on with the aim of producing optical filters and other accessories useful in the solar program. The overall solar program has been supervised directly by Dr. D. H. Menzel, who is also Chairman of the Committee on Scientific Operations for the High Altitude Observatory. Dr. H. K. Sen left the Observatory in June to accept a position at the National Bureau of Standards. Dr. Barbara Bell joined the staff in July.

Dr. Fred L. Whipple, Chairman of the Department of Astronomy in Harvard College, has continued his activities in the broad field of meteors. He has prepared the following summary of the year's progress:

Beginning on June 1, the Meteor Project began work on a new task with the Air Force — namely, the instrumentation of two Super-Schmidt meteor cameras for the photography of persistent meteor trains and the consequent recording of winds of the upper atmosphere. The

work of the main contract with the U. S. Naval Bureau of Ordnance was transferred in September 1951 to a similar contract with the Office of Naval Research.

During the past year approximately 300 meteors have been photographed on the project and 125 (more than twice as many as last year) doubly photographed at the two stations near Las Cruces, New Mexico. Particularly successful was the "T-Day" operation with various other agencies for the study of the upper atmosphere. This operation occurred near December 11 at the time of the peak of the Geminid meteor shower, at which time a number of rockets were fired at the White Sands Proving Ground and other upper atmospheric researches were made simultaneously in order to correlate the data at the same instant. We were very successful in that 86 meteors were doubly photographed during the interval from December 9 to December 15.

The first long-awaited Super-Schmidt meteor camera was completed by the Perkin-Elmer Corporation and flown to New Mexico late in May. The camera was put into full-time operation on July 1. It has proved to be as effective as expected and is now the outstanding instrument in the world for the photography of meteors. The second camera is still under construction but is expected in the late fall.

The major scientific result on the program concerns a systematic difference in the density of the upper atmosphere above 70 kilometers as measured over Massachusetts and over New Mexico. Preliminary reductions by Dr. Luigi Jacchia show that around the region of 75 to 100 kilometers the density of the air is greater over Massachusetts by approximately 0.2 in the logarithm. Seasonal variations in the densities of the upper atmosphere in New Mexico appear to follow much the same systematic trends as over Massachusetts. Numerous technical problems have been solved for the project in the past year and a number of scientific papers have been prepared and published.

Those working on the Meteor Project in Cambridge are: Dr. Fred L. Whipple, Miss Frances W. Wright, Mrs. Marilyn M. Benton, and Mr. Irwin Levitan (returned to Cambridge on September 1, 1951, after spending a year in New Mexico).

Those working on the Meteor Project at Las Cruces are: Mr. Philip Carroll, Mr. Gunther Schwartz, Mr. Robert Wells (went to New Mexico after working for Project in Cambridge until June 1951), Mr. Donald Mary (joined staff on September 23, 1951), and Mrs. Catherine Carroll (part time).

During the summer of 1951, Mr. Charles Whitney worked for the

Project in Cambridge and Mr. Henry J. Smith and Mrs. Elske v.P. Smith worked for the Project at Las Cruces. Mr. Richard E. McCrosky left the staff on August 7, 1951, to continue his studies in Harvard University. He was formerly Superintendent of the New Mexico meteor stations.

The following statement on the activities of the South African Station has been written by Dr. Bok, who returned in September from his eighteen months' visit to the Boyden Station:

The past year has seen the putting into operation of much of the new equipment for which we have been planning over the past decade. The Armagh-Dunsink-Harvard telescope of Baker-Schmidt design arrived in Bloemfontein late in October 1950. The telescope was mounted immediately upon arrival and the delicate optical and mechanical adjustments were made with great skill and painstaking care by Dr. Paraskevopoulos and his staff. By the first of December, the telescope was put into regular operation and since that date the ADH has produced without interruption, and without the need for further adjustment, excellent photographs of the southern sky. The total number of photographs made in the course of the first eleven months of operation is already in excess of eight hundred.

Defense priorities delayed the completion and delivery of the 33-inch objective prism for use with the ADH telescope. This large prism arrived only a few weeks before my departure from South Africa late in August. It had been damaged slightly in transit and a broken clamping ring had to be replaced, but five nights before my departure we succeeded in obtaining the first successful photograph with this prism, which is now producing regularly good quality spectra of faint stars. The ADH and its prism stand as a monument to the optical and engineering skill of the firm of Perkin-Elmer, who manufactured both items.

During the past year much use has been made of the photoelectric photometer that was brought to South Africa two years ago by Mr. Ivan R. King. The maintenance of this delicate piece of electronic apparatus has been put upon a routine basis and I am happy to report that our photometer has been used on all but two dark-of-moon nights from last December up to the present time. Because of the pressure of shop work caused by the arrival of the ADH and its prism, the mounting of the Stone spectrograph on the 60-inch reflector was postponed, but Dr. Lindsay reports that this project now has number one priority.

In the course of the past year progress has been made on several research projects. The planned observation with the ADH telescope under the "Center of Galaxy" Project has been completed as far as the regular blue and red photographs are concerned. The late arrival of the objective prism made it necessary to postpone the spectral classification program until next year. The photoelectric photometer on the 60-inch reflector has produced scientific results of a great variety. A guest observer from the University of Stellenbosch, Dr. G. G. Cillié, Jr., and I initiated observation of southern eclipsing variables. In the course of the year observations of light curves of eclipsing stars were completed for five objects with Dr. Cillié, Mr. Uco van Wijk (a Sheldon Fellow from Harvard), and our chief assistant Mr. Bester as principal observers. An attempt was made to check on possible flares in the nearby star Proxima Centauri. My own work with the photometer consisted principally of the establishment of accurate Southern Standards of magnitude for the "Center of Galaxy" Project and of color studies, jointly with Mr. van Wijk, of distant stars in southern Milky Way regions.

The work of the graduate students continues to be of satisfactory quality. Many have been called away to good positions before the completion of thesis work — a procedure that is flattering, but which has the obvious disadvantages of irregularity in examinations and remote-control of theses. Two student enterprises of an instrumental nature deserve mention: the rehabilitation and successful use of aluminizing equipment at the Oak Ridge Station by Harlan J. Smith and Franklin E. Kameny, and the installation by Richard Dunn on the ancient 15-inch refractor in Cambridge of a bi-refringent filter of his own construction with which solar spicules and prominences have been observed with remarkable clarity.

Members of the Observatory staff initiated and helped conduct a valuable conference on "The Sun in the Service of Man," held in February 1951 under the auspices of the American Academy of Arts and Sciences. The usual number of technical colloquia, special conferences, and Hollow Square meetings were held at the Observatory — sessions that were frequently flavored with the presence of distinguished visitors from American observatories and from abroad.

Again the nature and extent of the scientific work is indicated by the appended bibliography of papers published during the year by members of the Observatory staff.

HARLOW SHAPLEY, *Director*

Appendix to the Report on the Observatory

Publications for the Year 1950–1951

A. The following regular publications have been issued during the year by the Observatory.

Monographs:

No. 8. The Computation of Elements of Eclipsing Binary Systems. By Zdeněk Kopal.

Circulars: On Close Binary Systems.

No. 455. A Study of UX Ursae Majoris. By Albert P. Linnell.

No. 456. A Spectrophotometric Study of Zeta Aurigae. By Mario G. Fracastoro.

No. 457. The Effective Temperatures of Components of Eclipsing Binary Systems. By Zdeněk Kopal and Charlotte G. Treuenfels.

Quarterly Reports:

Nos. 4, 5, 6 and 14, American Association of Variable Star Observers. Margaret W. Mayall, Recorder.

Bulletins:

No. 920. Nineteen papers on variable stars, galactic structure, globular clusters, stellar spectra, and zenith distances by B. J. Bok, P. F. Bok, G. G. Cillié, R. J. Davis, S. Gaposchkin, D. Hoffleit, I. King, M. W. Mayall, V. McK. Nail, M. Olmsted, M. K. Vainu Bappu, U. van Wijk, and H. Zirin.

Announcement Cards:

Nos. 1102–1144. Reports on comets, novae, asteroids, variable stars, etc.

Reprints:

Nos. 338–351 and Series II, Nos. 34–36. Miscellaneous papers, all of which are listed below or in last year's report.

B. The following papers appeared in journals not published by the Observatory.

Bell, B. *See* D. H. Menzel.

Bok, B. J.

The Milky Way. Scientific American, Vol. 182, no. 2.

Dynamics and Evolution of Star Clusters. Sky and Telescope, Vol. 10, nos. 9 and 10; full articles in print in the series of Rubbi Lectures of the University of Stellenbosch (1950 series).

Progress of Photo-Electric Work at the Boyden Station. Monthly Notices of the Astronomical Society of South Africa, Vol. 10, no. 5.

The Cloud Structure of the Interstellar Absorbing Medium. Monthly Notices of the Astronomical Society of South Africa, Vol. 10, no. 7.

Fowler, F. E.

Servo Guider for Solar Telescopes. With D. S. Johnson. Electronics, Vol. 24, no. 5.

Gaposchkin, S.
Is CPD −60°3278 an Extraordinary Eclipsing Variable? Publications of the Astronomical Society of the Pacific, Vol. 63, no. 371.
The Changing Period of SV Centauri. Publications of the Astronomical Society of the Pacific, Vol. 63, no. 372.
Possible Apsidal Motion of the Eclipsing Variable BD +31°3932. Publications of the Astronomical Society of the Pacific, Vol. 63, no. 372.

Hoffleit, D.
The Discovery and Exploitation of Spectroscopic Parallaxes. Popular Astronomy, Vol. 58, nos. 9 and 10, Vol. 59, no. 1. (H.R. 342).
The "Josiah" and the "Joshua Bates" and the Meteoritic Dust Shower of November 14, 1856. Popular Astronomy, Vol. 59, no. 6.
The Library of the Harvard College Observatory. Harvard Library Bulletin, Vol. 5, no. 1.

Janssen, E. M. *See* D. H. Menzel.

Johnson, D. S. *See* F. E. Fowler.

King, I.
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Variable Star Notes. Nine articles in Popular Astronomy, Vol. 58. (H.R. 339).
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Menzel, D. H.
Weather Conditions for the Eclipse of February 25, 1952. With E. M. Janssen and B. Bell. Observatory, Vol. 71, no. 861.
Transfer of Radiation. II. Radiative Transfer in Absorption Lines. With H. K. Sen. Astrophysical Journal, Vol. 113, no. 3. (H.R. 350).
Transfer of Radiation. III. Reflection Effect in Eclipsing Binaries. With H. K. Sen. Astrophysical Journal, Vol. 113, no. 3. (H.R. 351).
Some Instruments for Solar Research. Sky and Telescope, Vol. 10, no. 8.

Nail, V. McK. *See* H. Shapley.

Sen, H. K. *See* D. H. Menzel.

Shapley, H.
NGC 1866 and the Magellanic Cloud Variables. With V. McK. Nail. Astronomical Journal, Vol. 55, no. 8. (H.R. Series II–36).
Proxima Centauri as a Flare Star. Proceedings of National Academy of Sciences, Vol. 37, no. 1. (H.R. 344).
Magellanic Clouds. I. Transparency. Proceedings of National Academy of Sciences, Vol. 37, no. 3. (H.R. 345).
Magellanic Clouds. II. Supergiant Red Variable Stars in the Small Cloud. With V. McK. Nail. Proceedings of National Academy of Sciences, Vol. 37, no. 3. (H.R. 346).
Galactic and Extragalactic Studies, XXI. Distribution of 95,000 Galaxies in the North Galactic Cap. Proceedings of the National Academy of Sciences, Vol. 37, no. 4. (H.R. 347).

Thomas, R. N. *See* F. L. Whipple.

Warwick, J. W.
Curve of Growth Polarization. Proceedings of National Academy of Sciences, Vol. 37, no. 4. (H.R. 348).

Whipple, F. L.
The Theory of Micro-Meteorites. I. In an Isothermal Atmosphere. Proceedings of National Academy of Sciences, Vol. 36, no. 12. (H.R. 343).
The Theory of Micro-Meteorites. II. In Heterothermal Atmospheres. Proceedings of National Academy of Sciences, Vol. 37, no. 1. (H.R. 343).
A Comet Model. II. Physical Relations for Comets and Meteors. Astrophysical Journal, Vol. 113, no. 3. (H.R. 349).
Comets. Scientific American, Vol. 185, no. 1.
Astroballistic Heat Transfer. With R. N. Thomas. Astrophysical Journal, Vol. 114, no. 3.
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ONE HUNDRED AND SEVENTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE

FOR THE YEAR ENDING SEPTEMBER 30, 1952

BY

HARLOW SHAPLEY

CAMBRIDGE, MASSACHUSETTS
PUBLISHED BY THE UNIVERSITY
1953

[*Reprinted from the Report of the President of Harvard College and Reports of Departments, 1951–52*]

Observatory

To the Provost of the University:

Sir, — A year of exceptional progress in the development of equipment and in the scientific activities of the Observatory closes my term as Director. Within the report year we can note among others the following items of growth.

1. A new high-speed spectrograph has been put in operation on the Rockefeller reflector at the Boyden Station, and a stellar polarimeter that was constructed in Cambridge has been sent to Harvard Kopje for work on the polarization of star light by interstellar dust — our first work of this kind in the southern hemisphere. And at this southern station five residences for the staff have been built — an important epoch in the 60-year history of the Boyden Station.

2. The new Baker Super-Schmidt cameras, unequaled anywhere for the study of meteors and meteor trains, have been installed and are in successful routine operation at the Soledad and Doña Ana Stations near Las Cruces, New Mexico. (Dr. Baker, Research Associate, has been awarded the Magellanic Prize of the American Philosophical Society for his conception and design of these unusual photographic cameras.)

3. During the past summer the mounting of the largest of coronagraphs has been shipped from the factory in California and installed in the conical turret at the Sacramento Peak solar station; and a dozen new buildings for residence, laboratory, and offices have been completed on the mountain top, to which a twenty-mile new road from Cloudcroft, New Mexico, has been built.

4. At the Agassiz Station (formerly called the Oak Ridge Station) a significant beginning has been made towards the installation of a 25-foot mirror (dish) for researches in radio astronomy; the road has been made through the woods to the selected site and the design and construction of the mirror, its mounting, and the "black box" — the heart of this new-type astronomical research instrument — are well along. The Agassiz

Station is the only astronomical observatory in America equipped with a radio telescope at this time.

5. At the Cambridge headquarters we can report the long-awaited receipt and installation of the large microdensitometer which will greatly strengthen our work in solar and stellar spectroscopy, and report also the purchase of an Eichner photometer for work on stellar magnitudes and the brightness of clusters and galaxies.

6. A refracting telescope of 29 inches aperture and about 80 feet focal length, with exceptional optical properties, has been designed by Dr. James G. Baker, Research Associate of the Harvard Observatory, and is now under construction. The precision nature of the lenses and mounting will make the instrument of great power in the study of fine detail on the sun's surface, e.g., for spicules and sunspot structure. It will also be unusually effective in work on planetary surfaces and for other researches requiring large scale, perfect achromatism, and high resolving power. It is proposed to mount the telescope (folded) on the 26-foot spar of the Sacramento Peak coronagraph where the altitude, latitude, and sky conditions justify such optical properties. A contract with the U. S. Air Force has made this undertaking possible.

7. And finally we should note that the resources of the Observatory have been increased during the past year by gifts of more than eighty thousand dollars, in addition to substantial receipts from government agencies for project research. These special incomes supplement our regular income from endowments and the contribution from Harvard College in support of the graduate and undergraduate instruction. The Observatory budget, this year as last, showed a small surplus in both restricted and unrestricted funds at the year's end.

It has indeed been a momentous year, and the years ahead should be rich in scientific returns. The total expenditure for instruments and buildings — for the coronagraph spar and its installation, the meteor cameras, the many new residences in South Africa and on Sacramento Peak, the radio telescope, the spectrographs and measuring engines — is well over half a million dollars. Also a considerable number of long-standing research enterprises have been finished or brought near completion, among

them the survey of the Inner Metagalaxy, the publishing of the Milton bureau study of the brighter variable stars, and the analysis of the classical cepheids of the Magellanic Clouds. My program on the extent of the Galaxy in the anti-center direction is within a year of completing its large quota of photographs with the Agassiz Station telescopes.

The growth of the Harvard Observatory during my term as Director has been made possible by the steady support of the University and of the numerous friends of the Observatory who have provided not only financial help but that generous and unfailing appreciation that is necessary to progress in the hard field of astronomical research. Throughout my term the friendship of George Russell Agassiz was outstanding; he shared the dreams and assisted in their realization. Grants-in-aid of special researches have come from many foundations, most substantially from the Rockefeller Foundation, the Research Corporation, the Guggenheim Foundation, and the American Philosophical Society. An equally important growth factor has been the industry and ability, in research and planning, of my numerous colleagues on the staff of the Observatory.

As specific items in the development of the astronomical work at Harvard I should like to refer to instruments, personnel, scientific programs, and financial resources.

In 1921 the Observatory's equipment included half a dozen photographic and visual instruments in Cambridge and four in Peru, where the Observatory's only out-of-town station was located. The largest instruments of that time were of 24-inches aperture, and the work was almost exclusively devoted to stellar magnitude standards, objective prism spectral classification, and the problems of variable stars. The Peruvian equipment (Boyden Station) was moved to South Africa in 1927 and new out-of-town stations were established in succession on Oak Ridge in the town of Harvard, Massachusetts; at Climax in the Colorado Rockies, for solar studies; near Las Cruces in New Mexico — a double station for the study of meteors; at Boulder in Colorado and on Sacramento Peak in New Mexico, for researches on the sun. The Climax and Boulder Stations have since been transferred to the joint ownership of Harvard University and the University of Colorado. The number of active telescopes and telescopic cameras has been increased from ten to more than

thirty, including two reflectors of 5-foot aperture, and several telescopes of special and unique character, such as the Baker-Schmidt two-mirror reflector in South Africa, the coronagraphs at Climax and Sacramento Peak, the meteor cameras at the Las Cruces stations, and the 25-foot aperture radio telescope for the Agassiz Station. The fields of theoretical astrophysics, cosmogony in its several phases, galaxies, meteors, optical design, and solar research have been added to the Observatory's scientific activities.

Since 1921 the staff has trebled in number, the permanent endowment of the Observatory has more than doubled, and the average annual expenditure during the past five years, largely on account of government contracts for solar and meteor research, is something like five times the amount at the beginning of my term. These pleasant fiscal statements are sadly shaded by the rise in the cost of labor, materials, and printing. The Observatory needs a substantial increase in endowment to maintain its increased plant and enlarged programs. The new administration will of course not only give special attention to rehabilitation of buildings and instruments, but make a new review of scientific programs and goals. Changes have been made frequently during my term or we could not have grown so notably; but in recent years the Council of the Observatory has properly postponed several items, especially in scientific policy, to the responsibility of a new regime.

Two activities of the Observatory remain to be mentioned in this brief review: the work and the training of graduate students and our cooperation internationally in various fields of astronomy. The graduate work in astronomy was inaugurated in 1923 and the first doctor's degree was given two years later. The school grew rapidly from the beginning, and in the interval from 1930 to 1945 approximately one-third of all doctor's degrees given in astronomy in America were from Harvard. Our influence on the science has been generally recognized. We have emphasized teaching as well as research, and our graduate students have now become important members in at least four other active graduate schools of astronomy in America. In fact our relative standing as a graduate school has been challenged by our own former students — a happy situation. Two research fellowships have been established at the Observatory — the Agassiz

and the Jewett — and the small Pickering Fellowship has aided in the advanced study of astronomy by women.

Traditionally the Harvard Observatory has been international in outlook. Observational material has been made available to various foreign astronomers, and programs, such as the spectral classification of faint catalogue stars for Yale and the Cape Observatory, and photographs to aid in the detection of proper motion stars for the University of Minnesota, have been carried through at considerable expense. The Observatory has long served as the western hemisphere agency for the distribution telegraphically of spot news on comets, asteroids, and other phenomena that require prompt reporting. Staff members have taken active part in a dozen international commissions of the International Astronomical Union. The most widespread and active international operation at the Observatory has been the founding here forty years ago and the building up and guiding of the American Association of Variable Star Observers. Both professional and amateur astronomers of a dozen different countries are involved in the systematic AAVSO programs on variable stars, sunspots, and aurorae. The main headquarters of the Association have always been at the Observatory and the Pickering Memorial Astronomer for the past two decades has been the Recorder of the organization and the editor of its numerous publications. Also during my term an amateur astronomical club named for the first two directors, W. C. and G. P. Bond, and the Amateur Telescope Makers of Boston have worked in their respective fields from the Harvard Observatory as headquarters.

Dr. Bok, who is in charge of the operations and programs of both the Boyden and Agassiz Stations, has prepared the following statement:

Dr. Eric M. Lindsay, Director of the Armagh Observatory in Northern Ireland, was Acting Superintendent of the Boyden Station during the period covered by the present report; he left at the end of September, 1952, to resume his duties as Director of the Armagh Observatory. Pending the appointment of a permanent successor to the late Dr. John S. Paraskevopoulos, Mr. Henry J. Smith assumes as of October 1, 1952, the functions of Acting Superintendent, with the assistance of Professor G. G. Cillié, Jr., from the University of Stellenbosch. The Boyden Station has been the

scene of much activity during the past year. The principal change in the physical plant has been the completion of three staff residences and a Visitors Hostel capable of housing the equivalent of two visiting astronomers and their families. These houses were built especially for our use at the expense of the Municipality of Bloemfontein; Harvard Observatory occupies these houses at rents which have been set by the Municipality at the lowest possible rates. In addition the Municipality is providing an annual grant for the Station to assist in scientific and other operations.

The preceding year was marked by the organization of a special committee of outsiders, distinguished South African citizens and Americans in South Africa, known as the "Friends of the Boyden Station." The Friends Committee has the dual purpose of assisting with the raising locally of much needed additional funds and of advising and assisting the Superintendent with regard to operational problems. The Committee has served admirably in both respects.

It was largely due to the efforts of the Committee of Friends that the South African Government provided a substantial grant toward the operation of the Boyden Station. The Friends Committee also proved invaluable with advice and assistance when a threat to construct a large military camp at the foot of Harvard Kopje developed.

For the first time, visiting scientists from Northern Ireland and from Eire spent time in residence at the Boyden Station to claim their share of the available observing time of the Armagh-Dunsink-Harvard telescope. The arrangements for joint operation of this powerful new Baker-Schmidt telescope are apparently working out quite satisfactorily. The excellence of the Boyden Station as a site for an astronomical observatory is becoming generally recognized. The Stockholm Observatory sent one of its chief observers, Dr. J. M. Ramberg, to the Boyden Station for four months to study our Station as a possible site for the erection of a new Swedish Schmidt telescope. Dr. Ramberg's report on the facilities available at our Station and on the excellence of our skies has apparently been a favorable one. Preliminary inquiries about the possibility of establishing one or more telescopes at the Boyden Station have come from three other northern hemisphere observatories.

Scientifically the greatest interest attaches to the putting into operation in the course of the past year of the Stone Spectrograph on the 60-inch Rockefeller Reflector. This instrument promises to be an important addition to the small number of spectrographs now in operation at South Hemisphere observatories. Apart from work on various routine programs at the Station, much progress was made in the course of the year with photoelectric studies of eclipsing vari-

ables and colors of cepheid variables. Programs related to the precision classification of stellar spectra continue to have a high priority.

The most interesting innovation at the Station has been the photography in hydrogen $H\alpha$ light of large sections of the southern Milky Way. This new survey is being carried out with a 3-inch Zeiss Sonnar lens of small focal ratio (f/1.5) on a personal loan from Mr. Richard S. Perkin. The Perkin-Zeiss camera, fitted with a suitable Baird interference filter, is proving to be a powerful tool for the detection of extended regions of ionized hydrogen. Through this survey progress is being made with the tracing of the inner spiral arm, or spiral arms, of our Milky Way system.

The most important event of the year at the Agassiz Station took place on Tuesday, May 13, when the name of the station was officially changed from *Oak Ridge* Station to the *George Russell Agassiz* Station, to honor the memory of a life-long friend and benefactor of the University and of the Observatory. Among those participating in the ceremony were Mr. Agassiz's widow, the President and the Provost of the University, members of the Governing Boards, members and friends of the Agassiz family, and the Observatory staff. Near the entrance to the station a simple stone with a plaque tells of Mr. Agasssiz and of what he has meant to the Observatory and to Harvard University.

The Agassiz Station continues to be an important observing center dedicated not only to scientific research, but also to the training as observers of graduate students and of selected undergraduates. There have been no changes in the major telescopes of the station, but every effort has been made to improve the efficiency of the existing equipment and special emphasis has been placed on the construction and maintenance of improved auxiliary equipment. The photoelectric photometer has been basically overhauled and we are now emphasizing continuous preventive maintenance; since early spring, when the photometer went back into full-time operation, there have been no breakdowns in our electronic equipment. The spectrograph is being adapted for work on radial velocities.

During the summer of 1952, we reinstated the traditional summer program at the Agassiz Station. Eleven graduate and undergraduate students were in residence as observers for appreciable periods and half a dozen visting astronomers spent from one or two days to thirteen days at the Station as guests of Harvard Observatory. In spite of poor observing weather during the first half of the summer, the group succeeded in completing half a dozen projects and in making good progress in another half dozen, mostly with the photo-

electric photometer and the spectrograph on the 61-inch Wyeth reflector and with the Jewett-Schmidt telescope.

In conjunction with the Agassiz Station summer program, a series of fourteen informal seminars was organized at the Observatory in Cambridge. The title of the series was "The Structure of the Galaxy"; the wholly voluntary attendance ranged from thirty to fifty at each seminar and approximately 170 copies of the mimeographed notes have already been distributed to astronomers everywhere. Two visitors' Open Nights were held at the Station, one for residents of Harvard, Massachusetts, associated with Harvard University, the other for the general public; both of these were well attended.

Buildings and grounds at the Agassiz Station are in excellent condition. In the course of the year the roads were resurfaced, the water system was thoroughly overhauled and a special room for the refrigerated storage of fresh photographic plates was fitted.

The greatest innovation at the Station is the plan for the erection of a radio telescope, equatorially mounted and fitted with a parabolic reflector of 25-foot aperture. The equipment will be used in conjunction with a Microwave Console (now being constructed by the Ewen Knight Corporation) capable of recording, with a high frequency resolution, galactic radiation in the frequency interval between 300 and 1600 Mc/sec. Present plans call for the new equipment to go into operation early in the spring of 1953. The initiation of this project was made possible by a large gift from a donor who desires to remain anonymous. The major expense is met by a substantial grant from the National Science Foundation.

Dr. Whipple has written the following brief account of the work which he supervises in the field of meteors:

During the past year the first two Baker Super-Schmidt Meteor Cameras, constructed by the Perkin-Elmer Corporation of Connecticut, have been put into opertaion in New Mexico for the Office of Naval Research. These instruments have proved even more effective than was expected in the photography of meteors. Since March, 1952, they have been photographing meteors at the rate of one per half hour of exposure time; the total through August has amounted to 347 doubly photographed at the two stations.

The technique of photographing persistent trains left by the brighter meteors was investigated during this period. Success in such photography is highly dependent upon the proper selection of photographic emulsions and upon special adaptation of the equipment for multiple photographs taken during the few seconds that the trains persist. The method adopted has proved to be a success-

ful one for measuring wind velocities in the upper atmosphere. The two Air Force Super-Schmidt Cameras, soon to be installed, will be used for this research.

Those working on the Meteor Project in Cambridge are: Dr. Fred L. Whipple, Miss Frances W. Wright, Miss Phyllis Edwards, Dr. Allan Cook, Dr. Salah Hamid, Mr. Irwin Levitan, and Mr. Arthur Partridge.

Those working on the Meteor Projects at Las Cruces are: Mr. Robert C. Wells, Mr. William Liller (who joined the staff on September 8, 1952), Mr. Jack Deskins, Mr. Edward Horine (who joined the staff on September 15, 1952), Mr. Elmore Mayhew, and Mr. Samuel Whidden.

During the summer of 1952, Mr. Richard E. McCrosky worked for the Projects in Cambridge, leaving the staff on September 26 to continue his studies in Harvard University. In New Mexico, Mr. and Mrs. Harlan J. Smith observed for the Projects during August.

The large programs of solar research include the activities in Cambridge as well as the observational work at the Sacramento Peak Station, and at Climax. Dr. Menzel summarizes the current activities as follows:

During the past year considerable progress has been made at Sacramento Peak, New Mexico, in the development of the Upper Air Research Station, operated under a contract with the U. S. Air Forces. The major building construction of offices, residences, dormitories, laboratories, maintenance, etc., is essentially complete. In addition, the 26-foot Spar, which will eventually hold the 16-inch coronagraph and other optical systems, is completed by Westinghouse and installed in the large conical dome. Optical parts for the main coronagraph are under construction at the High Altitude Observatory of Harvard University and University of Colorado, at Boulder, Colorado.

The High Altitude Observatory of Harvard University and University of Colorado has, throughout the year, maintained and operated the observing station at Climax, Colorado. The new site, approximately three miles from the original, is now fully occupied and the conical dome moved from the old to the new location. The old site is now completely abandoned and all work is carried on at the new location, which is appreciably freer from dust, smoke, and other atmospheric contaminations.

The coordination of observing programs at Sacramento Peak and at Climax, and the reporting of the daily observational results, have

been carried on through Boulder, which maintains daily radio contact with both of these stations.

Mrs. C. P. Gaposchkin's activities, in addition to research on the problems of stellar evolution, have this year included a series of lectures in the University of London on stellar evolution and the completion of her volume "Stars in the Making," published by the Harvard University Press as the ninth volume in the series of Harvard Books on Astronomy.

My own scientific program currently includes researches on the extent of the Galaxy in the anti-center direction, the corona of stars surrounding our galactic discoid, the distribution of some 300,000 galaxies in the "Inner Metagalaxy," and the structure and population of the Clouds of Magellan. An accounting of this work, and of the scientific work of some thirty others in the Observatory who have published scientific papers during the past year, cannot be included in this Annual Report. The bibliography which follows may serve to indicate the nature and extent of our investigations.

Harlow Shapley
Director

Appendix to the Report on the Observatory

Publications for the Year 1951–1952

A. The following regular publications have been issued during the year by the Observatory.

Annals:

Vol. 118, Nos. 1–27. Variable Stars in Milton Fields Nos. 27–1. By Cecilia Payne-Gaposchkin and Sergei Gaposchkin.

Quarterly Reports:

Nos. 7, 8, 9, 10, 11, 12, 13, 15. American Association of Variable Star Observers. Margaret W. Mayall, Recorder.

Bulletins:

No. 921. Nine papers on variable stars, stellar spectra, stellar magnitudes, stellar polarization and interstellar material by D. Hoffleit, V. McK. Nail, J. M. Newkirk, U. van Wijk, C. A. Whitney and H. Zirin.

Announcement Cards:

Nos. 1145–1190. Reports on comets, novae, asteroids, variable stars, etc.

Reprints:

Nos. 352–366 and Series II, Nos. 37–42. Miscellaneous papers, all of which are listed below or in last year's report.

B. The following papers appeared in journals not published by the Observatory.

BELL, B.

Solar Variation as an Explanation of Climate Change. Symposium on Climate, American Academy of Arts and Sciences (in press).

BHATNAGAR, P. L.

Preliminary Report on the Dynamics of Ionized Media. With M. Krook and D. H. Menzel. Proceedings of the General Assembly of International Scientific Radio Union (in press).

Internal Constitution of the Sun and Climatic Changes. Symposium on Climate, American Academy of Arts and Sciences (in press).

BOK, B. J.

The Depths of the Milky Way. Popular Astronomy, Vol. 59, No. 10.

The Southern Sky. Scientific American, Vol. 186, No. 7.

Studies of the Southern Milky Way. Proceedings of the American Philosophical Society, Vol. 96, No. 5. (H.R. Series II–42).

Photo-electric Colors of B Stars in Five Regions of the Southern Milky Way. With U. van Wijk. Astronomical Journal, Vol. 57, No. 7.

See also F. W. Wright.

BURBIDGE, E. M. *See* G. R. Burbidge.

BURBIDGE, G. R.

The Equation of Transfer and the Residual Intensities in Spectrum Lines. With E. M. Burbidge. The Astrophysical Journal, Vol. 116, No. 1. (H.R. 366).

CARROLL, P.

Equipment and Technique for Molding Spherically-Curved Film. With R. E. McCrosky, R. C. Wells, and F. L. Whipple. Photographic Science and Technique, Section B of Photographic Society of America Journal, Vol. 18, No. 3.

Film Molding and Photographic Accessories for the Super-Schmidt Meteor Cameras. With R. E. McCrosky, R. C. Wells, and F. L. Whipple. Technical Report No. 8, Task I of NOrd 10449 for the U. S. Naval Bureau of Ordnance and N50ri–07647 for the Office of Naval Research. (H.R. Series II–39).

DUNN, R. B.

How to Build a Quartz Monochromator for Observing Prominences on the Sun. Seven articles in Sky and Telescope, Vol. 10.

EVANS, J. W.

Flash Spectrum Expedition. Sky and Telescope, Vol. 11, No. 9.

Solar Flares. Scientific American, Vol. 185, No. 6.

The Solar Flare Recorder of the Sacramento Peak Station of the Harvard College Observatory. Science, Vol. 114, No. 2969.

FOWLER, F. E.

Accurate Time for Scientific Observations. Electronics, January, 1952.

HAMID, S. E. *See* F. L. Whipple.

HEARN, A. B. *See* H. Shapley.

KIEWIET DE JONG, J. H.

Three-Star Position Tables for Air Navigation. Journal of the Institute of Navigation, Vol. 5, No. 1. (H.R. 357).

KING, I.

A Note on the Concept of Effective Wave Length. The Astrophysical Journal, Vol. 115, No. 3. (H.R. 362).

KROOK, M.

Interstellar Matter and the Solar Constant. Symposium on Climate, American Academy of Arts and Sciences (in press).

LUYTEN, W. J.

Forty-four New White Dwarfs in the Southern Hemisphere. Proceedings of the National Academy of Sciences, Vol. 37, No. 10. (H.R. 353).

New White Dwarfs in the Southern Hemisphere: Second List. Proceedings of the National Academy of Sciences, Vol. 38, No. 6. (H.R. 365).

MAYALL, M. W.

Variable Star Notes. Ten articles in Popular Astronomy, Vol. 59 (H.R. 356).

Variable Star Notes. The Journal of the Royal Astronomical Society of Canada. Vol. 46, Nos. 4 and 5.

MCCROSKY, R. E. *See* P. Carroll.

MCVITTIE, G. C.

A Model of a Spiral Galaxy. With C. Payne-Gaposchkin. Monthly Notices of the Royal Astronomical Society, Vol. 111, No. 5. (H.R. 358).

MENZEL, D. H.

Bernard Lyot. Sky and Telescope, Vol. 11, No. 8.

Those Flying Saucers — An Astronomer's Explanation. Time Magazine, Vol. 59, No. 23.

The Truth about Flying Saucers. Look Magazine, Vol. 16, No. 13.

On the Causes of the Ice Ages. Symposium on Climate, American Academy of Arts and Sciences (in press).

Mathematical Physics. Prentice-Hall (in press).

NAIL, V. MCK. *See* H. Shapley.

ÖHMAN, Y.

Some Observations of Dark Filaments in Prominences. The Astrophysical Journal, Vol. 114, No. 2. (H.R. 354).

PAYNE-GAPOSCHKIN, C.

Stars in the Making. The Harvard Books on Astronomy. The Harvard University Press.

Variable Stars and Galactic Structure. Nature, Vol. 170, No. 4319. (H.R. 364).

"Worlds in Collision." Proceedings of the American Philosophical Society, Vol. 96, No. 5. (H.R. Series II–41).

ROBERTS, W. O.

Sunspot Prominences and the Yellow Coronal Line. The Astrophysical Journal, Vol. 115, No. 3.

SHAPLEY, H.

Comparison of the Magellanic Clouds with the Galactic System. Publications of the Observatory of the University of Michigan, Vol. X (H.R. Series II–37).

Smog in Space. Science, Vol. 113, No. 2934.

More Probes into Interstellar Space. Science, Vol. 113, No. 2939.

Flare Stars and the Radio. Science, Vol. 113, No. 2945.

A Survey of the Inner Metagalaxy. The American Scientist, Vol. 39, No. 4. (H.R. 352).

Magellanic Clouds. III. Differential Absorption within the Large Cloud. With V. McK. Nail. Proceedings of the National Academy of Sciences, Vol. 38, No. 4. (H.R. 359).

Magellanic Clouds. IV. On the Period Frequency Anomalies. With V. McK. Nail. Proceedings of the National Academy of Sciences, Vol. 38, No. 4. (H.R. 360).

Two Period-Frequency Anomalies for Classical Cepheids. Sky and Telescope, Vol. 11, No. 11.

Galactic and Extragalactic Studies, XXII. The Extent of the Galaxy in the Anti-Center Octant. With A. B. Hearn. Proceedings of the National Academy of Sciences, Vol. 38, No. 10.

THOMAS, R. N.

The Physical Theory of Meteors, II. Astroballistic Heat Transfer. With F. L. Whipple. The Astrophysical Journal, Vol. 114, No. 3. (H.R. 355).

VAN WIJK, U. *See* B. J. Bok.

WELLS, R. C. *See* P. Carroll.

WHIPPLE, F. L.

On the Origin of the Taurid Meteor Streams. With S. E. Hamid. Helwan Observatory Bulletin, No. 41. (H.R. 361).

Results of Rocket and Meteor Research. Bulletin of the American Meteorological Society, Vol. 33, No. 1. (H.R. Series II–40).

Astroballistic Heat Transfer. With R. N. Thomas. Journal of the Aeronautical Society, Vol. 18.

Exploration of the Upper Atmosphere by Meteoritic Techniques. Advances in Geophysics. Academic Press.

Meteoritic Phenomena and Meteorites. The Physics and Medicine of the Upper Atmosphere. The Lovelace Foundation.

Meteor Observations and their Interpretations. Transactions of the American Geophysical Union, Vol. 32.

WOLBACH, J.

The Insufficiency of Geographical Causes of Climatic Change. Symposium on Climate, American Academy of Arts and Sciences (in press).

WRIGHT, F. W.

The Photographic Leonid Meteors. Technical Report No. 7. Task 1 of NOrd10449 for U. S. Naval Bureau of Ordnance and N5ori–07647 for the Office of Naval Research. (H.R. Series II–38).

Selecting the Moon's Limb. Journal of the Institute of Navigation, Vol. 5, No. 2. (H.R. 363).

Revision of Basic Marine Navigation. With B. J. Bok. Houghton Mifflin Company.

HARVARD
ASTRONOMICAL OBSERVATORY

ANNUAL REPORT

1953

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Harvard College Observatory

To the Dean of the Faculty of Arts and Sciences:

Sir, — I am pleased to submit this annual report on behalf of and with the advice of the Harvard College Observatory Council, consisting of Professor Bart J. Bok, Dr. Cecilia Payne-Gaposchkin, Professor Fred L. Whipple, and myself, Donald H. Menzel, Chairman. The report covers the activities of the Observatory and its associated Stations during the year 1952–53. Upon the retirement of the former Director on September 1, 1952, I was asked to serve as Acting Director.

Probably the most significant factor in establishing the course for the year was the report of the ad hoc committee, which set forth the following criticisms:

1) that equipment at the Agassiz Station is inadequate and of inferior quality for training of graduate students.

2) that the Observatory is inadequately staffed, especially in the younger or junior scientific grades.

3) that an estimated $300,000 would be necessary for adequate rehabilitation of equipment at the Agassiz Station, with emphasis on strengthening the program of training in observational astronomy.

4) that effective operation of the Boyden Station, based on interchange of personnel between Bloemfontein and Cambridge, would require an additional annual budget expenditure of $30,000, with further expenditure for improvement of instrumentation to the extent of a capital investment of $100,000 to $200,000.

The Corporation, in line with the committee's report, set aside $300,000 to be used to improve the graduate training program and to rehabilitate observing facilities at the Agassiz Station.

On January 14, 1953, President Conant announced for the Corporation that the cost of full-time operation of the Boyden Station in South Africa by Harvard was too great a burden for

the Observatory budget. Continued limited operation was authorized until June 30, 1954. A solution is still being sought by which the Station can continue to operate, possibly on a cooperative basis under joint management. Meanwhile, the astronomers of South Africa and the "Friends of the Boyden Station" have provided both moral support and financial assistance.

Various European observatories have expressed an interest in the Boyden site. The Harvard College Observatory Council hopes that Harvard's investment in the Boyden Station will enable them to retain certain rights to telescope time, without requiring continued responsibility for maintenance or overhead. Furthermore, the Council has noted the overall shortage of astronomical equipment available for study of the southern sky and fully recognizes that many basic researches could be undertaken in this area with adequate, modern equipment.

Architect's plans are being prepared for a new and modern structure to replace the old Building A; the new building will contain offices, classrooms, storage and research facilities. The Corporation has authorized the expenditure of $150,000 of the $300,000 previously allocated to the Agassiz Station, for this building and for other improvements to existing facilities in Cambridge. Renovation of a tin building previously used for storage has already been started, and will provide space for a machine shop, previously housed in "Building B," which was condemned several years ago. The tin building will also house an optical shop previously located in the basement of Building A. It is hoped that the Amateur Telescope Makers of Boston will continue to avail themselves of these facilities. Several small wooden sheds, one fire-damaged and the others beyond repair, are also scheduled for early demolition.

Guided by the ad hoc report and the Corporation's decisions, the Council has continually sought ways to retrench and adjust the scientific programs without serious curtailment, and has succeeded in ending the fiscal year with a balanced budget.

Among the changes and additions to the physical plant are the following:

1. Installation of a radio telescope at Agassiz Station.

2. A fourth super-Schmidt Meteor camera installed near Las Cruces, New Mexico, for photographing meteor trains.

3. Tube sensitometer installed at Sacramento Peak, New Mexico.

4. Jam Handy analyzing projector (35 mm) at Cambridge.

5. Microfilm camera and reader at Cambridge.

6. Thorough reconditioning of the five small telescopes at Agassiz Station.

7. Renovation of the first floor, Building C (Cambridge), into two offices and a tutorial library and seminar room.

8. Redecoration of nine offices, a supply room and a publications mailing room.

9. Conversion into offices of an entire floor in Building D, previously devoted to plate storage.

10. Modernization of the 100-year-old, 15-inch telescope into an important research instrument. The optical system was designed by Dr. J. G. Baker, Research Associate, and constructed by R. B. Dunn, graduate student, with the active cooperation of Mr. Chester Cook and Mr. James Gagan of the Amateur Telescope Makers. The project, which is still in progress, was made possible by gifts from various persons interested in the work of the Observatory. The optical parts will be tested by Mr. Dunn at Sacramento Peak, New Mexico, and used for a special program of solar research.

11. Consolidation of library, with complete physical inventory of holdings. New catalog and shelf list. This project was carried out under the guidance of Mr. K. D. Metcalf, Widener Library.

12. Cleaning and consolidation of the photographic plate collection.

13. Installation of the Eichner photometer at Cambridge.

14. An Observatory lantern slide library set up of about 3000 lantern slides (2 x 2 inches).

15. Installation of new heating equipment to replace worn out and defective equipment.

Most of the research projects reported previously have been continued and furthered during the year. Several new members have been added to the scientific and teaching staff, with a resulting broadening of the scientific program.

Professor Harlow Shapley lectured in Cosmography in the

Department of General Education in Harvard College. At the Observatory, he and his staff continued their researches on the external galaxies and the form and extent of the Milky Way. The work is centered on the photometric measures of globular clusters in the Magellanic Clouds, and on novae, cepheids, long-period variables, and other special types of objects in those systems. Details of the researches are presented in the dozen technical papers written during the report year. Here we name the five principal investigations currently in progress.

1. A study of the constellations, emission nebulae, cepheid variables, and dimensions of the Magellanic Clouds — a research supported in part by the Office of Naval Research and the American Philosophical Society.

2. Further exploration of the stellar corona surrounding the galactic discoid — an investigation supported in part by a grant from the National Science Foundation.

3. Measures of the extent of the Galaxy in the anticenter direction, based on the cepheid-galaxy method with photographs made chiefly at the Agassiz Station.

4. The Inner Metagalaxy studies on the distribution and other properties of half a million galaxies nearer than 250 megalight-years.

5. Delineation of the borders of the southern Milky Way's zone of avoidance for galaxies. This research and the two preceding have been assisted by an anonymous gift.

Mrs. Virginia McKibben Nail has been the principal collaborator in the many studies of the Magellanic Clouds. Mr. Henry A. Sawyer at the Agassiz Station and Mr. M. J. Bester at the Boyden Station have been the chief observers for projects where new photographic material was required. Miss Ann B. Hearn has been chief assistant in the work on galaxy distribution and cluster type variables.

Professor Bart J. Bok supervised the activities of Boyden Station, Bloemfontein, South Africa, and the observational program at Agassiz Station, Harvard, Massachusetts, the two stations providing astronomical photographs of the southern and northern skies, respectively.

The decision of the Corporation to transfer responsibility

for operation of the Boyden Station has necessarily resulted in the changing, curtailment, or deferment of certain research programs. No permanent Superintendent has been appointed to replace the late Dr. John S. Paraskevopoulos, who, for more than twenty-five years, directed the affairs of the Boyden Station. Dr. Eric M. Lindsay, Acting Superintendent from September 1, 1951 to October 1, 1952, resigned to return to Armagh Observatory in North Ireland. His place was taken by Mr. Henry J. Smith, graduate student from Harvard College Observatory, who was accompanied to South Africa by his wife, Elske, also a graduate student. The Harvard College Observatory Council has asked Mr. Smith to continue as Acting Superintendent until June 30, 1954. Other staff changes at Boyden include the resignation of Mr. Willem D. Victor, observing assistant for seven years, and his replacement by Mr. T. Houck, University of Wisconsin; the resignation of junior observing assistant, Peter Payten, without replacement. As indicated above, the Council is exploring various possibilities for transferring Boyden Station to other management, with special arrangements for obtaining desirable observational data from the southern hemisphere. A Committee appointed by the International Astronomical Union (I. A. U.) is studying ways and means of keeping the southern hemisphere observatory in operation.

The past year has seen the rounding off of several research programs based on the Boyden observations. The photography in hydrogen H-alpha light of faint southern emission nebulae, employing the Perkin-Zeiss camera to which reference was made in last year's Annual Report, has been nearly completed. A comprehensive paper on the results of this survey, by Professor Bok, M. J. Bester, and C. M. Wade, is about to go to press. The further program of H-alpha photography, utilizing the Armagh-Dunsink-Harvard telescope and the 60-inch Rockefeller Reflector, is being continued at the request of a Commission of the I. A. U. Progress on this program has been satisfactory. The related limited program of securing spectra for the classification of some of the stars responsible for the nebular excitation as well as photoelectric colors, is well on the way to completion.

Poor weather between September and December 1952 interfered with the Magellanic Cloud programs of Professor Shapley and of Dr. S. Gaposchkin and Dr. C. H. Payne-Gaposchkin. We

hope to complete these programs this year. Good progress was made by Mrs. Elske van Panhuys Smith with her thesis project of measurements of polarization of southern stars (60-inch Reflector) and on two projects of Mr. Henry J. Smith, the spectroscopic study of southern Wolf-Rayet stars and spectroscopic and other studies in the infra-red, especially for the region of the galactic center. Other researches include color-magnitude arrays in two globular clusters (Dr. C. H. Payne-Gaposchkin), bright eclipsing variables in the Magellanic Clouds (Dr. S. Gaposchkin), colors of Magellanic Cloud clusters (Mrs. Smith), studies of variable stars (Professor Shapley) and stellar distribution in the South Galactic Polar Gap (Professor Shapley and Professor Bok). Professor G. G. Cillié, Jr. of the University of Stellenbosch has again been a guest observer on the 60-inch Rockefeller Reflector, concentrating on photoelectric light curves of eclipsing binaries, and Dr. Arthur Code and his associate Mr. T. Houck of the University of Wisconsin were also at Boyden Station as guest observers.

We have been able to provide only routine maintenance for the equipment at Boyden Station this year. The aluminized coat of the primary mirror of the Armagh-Dunsink-Harvard telescope requires replacement. Since no suitable aluminizing tank is available in South Africa, plans are under way to provide for silvering of the mirror.

Action on the recommendation of the ad hoc committee to rehabilitate the instruments at Agassiz Station and to expand the program for students in observational and experimental astronomy has been deferred, pending the appointment of a permanent Director of Harvard College Observatory. In the interim, equipment at the Agassiz Station has been kept in good running condition and the telescopes are all in use. The five smaller instruments have been thoroughly cleaned, rewired, and rehabilitated by Harvard Department of Buildings and Grounds. Numerous observing projects are being pursued with the participation of graduate and undergraduate students, on a regular observing schedule. Pending final decision concerning the instrumentation at the Agassiz Station, graduate students have not been encouraged to undertake new observational projects, which conceivably could be disrupted by change in the equipment.

In the course of the past year observations were essentially

completed for three doctoral theses. Improvements were made in the photoelectric and spectrographic equipment for the 61-inch reflector. At present, three major groups of programs are in effect:

1. The completion of Professor Shapley's observational programs with the 16-inch Metcalf and with the Jewett-Schmidt telescopes (variable stars and galaxies);

2. Professor Bok's photoelectric program of magnitude standards in the Harvard C Regions;

3. Mr. William Tifft's project of adapting the Jewett-Schmidt telescope for three-color photometry according to the scheme of Wilhelm Backer (supplemented by photoelectric standardization).

The radio telescope, reported under construction at Agassiz Station last year, has been completed. The electronic equipment, constructed by the Ewen-Knight Corporation, appears to be functioning satisfactorily. The mounting and drive also have proved to be satisfactory. Dr. Harold I. Ewen continues to be formally associated with the project. We are employing a half-time junior electronic engineer, Mr. John A. Campbell, and the operation of the equipment is in the hands of three advanced students, two of them gathering material for doctoral theses in the field of 21 cm cosmic hydrogen radiation. The initial construction of the radio telescope was made possible by a grant from the National Science Foundation, supplemented by a gift from an anonymous donor. This same donor has generously provided two supplementary gifts for operation. The testing period appears to be approaching completion and the planned program of research will be initiated at an early date.

During the past year, a friend of the Agassiz Station, who wishes to remain anonymous, has given the Station an endowment of $100,000, the income from which will supplement the present annual budget of the Station and thus provide for continued further development.

At the meteor stations near Las Cruces, New Mexico, Professor Whipple reports that four Baker Super-Schmidt cameras photograph meteors at a phenomenal rate. Over a 17-month period, more than 2000 meteors have been recorded simultaneously from

the two stations by cameras equipped with rotating shutters. This work is carried on under the sponsorship of the Office of Naval Research and the Air Force.

In June, 1953, the fourth Super-Schmidt meteor camera was installed in New Mexico. This is the second camera under our contract with the Air Force, and will be used for the purpose of photographing the persistent trains left behind bright meteors. Five such multiple-train photographs of winds in the upper atmosphere have been reduced and analyzed by Whipple and Liller. Several others were photographed during the Perseid shower in 1953.

In April 1953 a group of analysts, headed by Dr. L. Jacchia, which had been located at the Massachusetts Institute of Technology, moved to new quarters at Harvard College Observatory. Their work of analyzing photographic meteor data is carried on under a contract with the U. S. Army Office of Ordnance Research. Their transfer to Harvard Observatory makes possible a closer coordination between the observational and analytical phases of the photographic meteor studies.

An analysis of 146 photographic meteor orbits, based upon the previous studies and analyses under the direction of Dr. L. Jacchia, was completed last summer by Professor Whipple. For the first time, a sufficient number of accurately-determined meteor orbits is available to provide a scientific discussion concerning the origin of these small bodies.

Various publications on comets and meteors have been prepared by Dr. R. N. Thomas, Dr. Allan Cook, Mr. Henry J. Smith, Mr. Harlan J. Smith, Mr. Richard E. McCrosky, Dr. L. Jacchia, Miss Frances W. Wright, Dr. Frank J. Kerr, Dr. P. L. Bhatnagar, Dr. William Liller, and Professor F. L. Whipple. Several collaborative programs of research on the nature of meteors and of meteoric phenomena have been undertaken, in particular between the Harvard group and the radio meteor group under the direction of Dr. P. M. Millman at Ottawa, Canada. Further collaboration has taken place with Professor Arthur Kantrowitz of Cornell University with regard to the shock-wave phenomena in meteors and between Dr. R. N. Thomas and the Hyperballistic Group at the Naval Ordnance Test Station at Inyokern, California. The foundations have been laid for deeper study and understanding of the nature of the

meteoroid, the physical processes of meteoric phenomena, the distribution of meteoritic materials within the solar system, and the origin of comets and meteoric material.

The following people have worked on the Meteor Project in Cambridge during the past year: Professor Fred L. Whipple, Miss Frances W. Wright, Dr. Allan Cook, Dr. Salah Hamid, Mr. Robert Hughes, Mr. Fred Franklin, Mr. Richard E. McCrosky, Mrs. Dorothea Greene, and Mrs. Mary B. DeVeber. In Las Cruces, the following persons have been associated with the project during the year: Dr. William Liller, Mr. Samuel B. Whidden, Mr. Arthur Partridge, Mr. Jack Deskins, Mr. Elmore Mayhew, Mr. Kenneth Morrison, Mr. Harry Emerson, Mr. Donald Smith, and other casual employees in capacities of secretary, plate molders, and plate inspectors.

The Harvard group working on solar research has continued to develop studies in this field, at the Upper Air Research Observatory at Sacramento Peak, Sunspot, New Mexico, and at the High Altitude Observatory of Harvard University and the University of Colorado, at Climax and Boulder, Colorado. The former station is operated under Air Force sponsorship and under an Air Force contract. The latter is operated as a non-profit corporation, with trustees appointed by the presidents of the two universities. Funds for operation have come mainly from gifts, grants in aid, or special government contracts.

Dr. John W. Evans, a Research Associate of Harvard College Observatory and previously Assistant Superintendent of the High Altitude Observatory, was appointed by the Air Force as Resident Superintendent of the Sacramento Peak Station.

On each clear day, the observers at Sacramento Peak photograph the spectrum of the solar corona at a fixed height above the limb of the sun. The photographic plates are processed immediately, washed and dried, so that data on the intensity of the corona may be obtained at once and forwarded daily by radio to the Central Radio Propagation Laboratory of the National Bureau of Standards. At the Bureau, the coronal intensities are used for predictions of the quality of long-distance radio communication. During this report period, 479 plates were obtained on 67% of the days. Of the plates taken, 60% were of standard weight. This program parallels a similar one at Climax, Colorado and the solar studies are closely coordinated.

Dr. Ching-Sung Yü remeasures and checks the intensities, and compares the results with those obtained at Climax.

In residence at Sacramento Peak are Dr. James Warwick and Dr. Constance Warwick, both Research Assistants working with the observational data. Dr. James Warwick has developed a technique for reducing the photographic density of the coronal emission lines to numbers representing the intensity of the coronal emissions on a uniform scale. He is studying flares on the sun in an effort to determine their probable shape, and has been developing the theory of profiles of absorption lines. Dr. Constance Warwick has been studying statistically the characteristics of solar flares associated with radio noise and with radio fadeouts. This comparative study is made possible because instruments for recording both visual and radio noise from the sun are in operation at the Peak. The comparison of motion picture and radio records of surges, eruptive prominences, and limb flares are part of this program.

From the movies of solar activity during recent months, as observed at Sacramento Peak, we are compiling two 800-foot 16 mm. black-and-white silent films to show the most spectacular observations of prominences and flares. One reel will be titled "Prominence Activity" and the other, "High-Quality Spicules and Chromosphere." Both films will be ready for public showing in the fall of 1953.

Mr. Harry Ramsey is the Observer-in-Charge at Sacramento Peak, assisted during the year by Mr. George Schnable, Mr. Harry Crawford, Mr. Edward Bergstrom and Mr. James Foster.

A number of scientists have been working in Cambridge under Contract AF19(604)–146. The studies undertaken have covered a wide variety of fields. Professor Menzel and Dr. Max Krook, continuing to develop fields previously studied in collaboration with Dr. P. L. Bhatnagar, have been studying varied problems in the field of magnetohydrodynamics. These studies, based on an interpretation of the observational data from Sacramento Peak and Climax, have led Professor Menzel, Dr. Max Krook, and Dr. Richard N. Thomas toward the development of a quantitative theory of prominence formation, including an identification of the forces active in the expulsion of solar eruptions as electromagnetic in character. The analyses have led to a quantitative interpretation of the observational data in terms of electric cur-

rents flowing in the solar atmosphere, forces of interacting magnetic fields, and a phenomenon called the "pinch effect." Many of the peculiar features of solar prominences appear to possess a reasonable and natural explanation in terms of the quantitative theories developed from a study of the magnetic fields. Dr. David Layzer, who joined the group late in the fall, has carried out an idealized series of studies under the general title "Linear Flame Propagation." These studies, though initially confined to a specific problem, appear to have some applications to solar physics. Dr. David Layzer has, in addition, been surveying the problems of observation and theory of solar phenomena, and his views on the initiation of a long-range program of observational and theoretical solar research have been inspiring to the group. During the year we have issued seven Scientific Reports under Contract AF19(604)–146.

Professor Menzel has also been developing a theory of generalized magnetic fields throughout the universe, from star to galaxy. Professor Menzel, Dr. P. L. Bhatnagar of St. Stephen's College, Delhi, India and Dr. Hari K. Sen of the National Bureau of Standards have collaborated in the preparation of a monograph on the subject of "The Internal Constitution of the Stars." This study, which reviews the whole field of stellar constitution from the standpoint of modern astrophysics, is nearing completion. Professor Menzel and Dr. H. K. Sen have also been developing a theory of Matrices, as applied to problems in optics, with special reference to crystal optics. Professor Menzel has also been studying the origin of cosmic rays, with particular emphasis on the solar origin.

Sacramento Peak, Sunspot, New Mexico, was the setting for a series of solar seminars in August and September 1953. The participants, including Professor Menzel, Dr. Max Krook, Dr. C. H. Payne-Gaposchkin, Dr. Barbara Bell, Dr. Richard N. Thomas, Dr. James Warwick, Dr. J. W. Evans, and others, discussed a variety of problems significant to solar observations and to the interpretation of such observations. We hope to repeat these conferences from time to time.

Statistical studies of solar activity, carried on by Dr. Barbara Bell and Mr. Harold Glazer, have led to a definition of many problems of solar activity, especially those relating to the problem of solar-terrestrial relationships. Most of these studies

are of a continuing nature, and the results obtained to date are only preliminary.

In brief summary, one may state that, during the past year, significant progress has been made in the understanding of solar phenomena from the viewpoint of modern spectroscopy, atomic physics, and magnetohydrodynamics. These studies, also, are continuing and future reports will undoubtedly carry reference to them.

Professor Menzel explored the highly popular subject of "Flying Saucers." This culminated in a book on this subject, which showed that the phenomena generally reported under this name usually result from some of the less familiar phenomena of meteorological optics.

Dr. Walter Orr Roberts, Director of the High Altitude Observatory of Harvard University and University of Colorado, and Research Associate of Harvard University, lists as the biggest achievement for the year completion of the building fund for the new turret and enclosure for the 16-inch coronagraph at Climax. The sum raised for this project totals $147,000. The funds were raised with the active cooperation of Mr. Paul Hammond, member of the Visiting Committee of Harvard Observatory. Work on the building has begun.

Miss Dorothy Trotter of the Boulder staff has moved her office to the recently dedicated Sommers-Bausch Observatory, where a radio transmitter has been conveniently installed. Miss Trotter and her assistants transcribe the daily data radioed from Climax and Sacramento Peak for re-transmission to the Central Radio Propagation Laboratory of the National Bureau of Standards, Washington, D. C.

High Altitude Observatory, assisted by University of Colorado, acted as host to the American Astronomical Society in Boulder, August 26–30, 1953. Delegates to this meeting included staff members of Harvard College Observatory and Sacramento Peak Station.

Most recent addition to the High Altitude Observatory staff is Dr. Jean-Claude Pecker of the Institute d'Astrophysique, Paris, France. He and Mrs. Pecker plan to stay at the Observatory for at least a year.

The cooperative arrangement between the High Altitude Observatory and scientific departments of various universities

of the Rocky Mountain region should be noted. During the year, three theses were written on the basis of work performed under the supervision of the High Altitude Observatory.

Russell Grant Athay: "Emission in the Hydrogen Balmer Lines and Continuum in the Flash-Spectrum of the 1952 Total Solar Eclipse at Khartoum, Sudan." University of Utah, Ph.D., July 1953.

John Anthony Cape: "Analysis and Critique of the Envelope-Tracing Method for the Investigation of Solar Prominences." Montana State College, M.S., June 1953.

The first summer session ever held by High Altitude Observatory for graduate students was conducted during the summer of 1953 by Dr. Walter O. Roberts, Director, and Dr. Richard N. Thomas, Lecturer, Harvard College Observatory, Cambridge, Massachusetts. This summer graduate students from Johns Hopkins University, the University of Indiana, the University of Wisconsin, Harvard University, the University of Utah, and the University of Colorado participated. The summer program centered on solar research, with particular attention on the analysis of data obtained by High Altitude Observatory at the total solar eclipse in February 1952 in Khartoum, Sudan. The analysis produced preliminary values of temperature, electron density, and departure from thermodynamic equilibrium in the solar atmosphere. The material will be published in a monograph. Study of the hydrogen chromosphere will be continued during the next academic year, both at Boulder and at Cambridge.

In addition to his work on the eclipse data and other solar problems, Dr. Richard N. Thomas carried a full teaching schedule at Harvard and continues research on astroballistics (i.e., meteors and ultra-speed ballistics). He has accepted a three-year appointment as Lecturer in Astronomy. He has resigned as Associate Professor of Mathematics and Astronomy in the University of Utah to accept this post.

Dr. Dorrit Hoffleit reports progress in her work on the nebulosities and associated early-type stars in Carina and a brief, similar examination of four fields in Sagittarius for comparison and contrast. A report of this investigation appears in Harvard Annal 119, No. 2. Miss Hoffleit, with Miss Lippincott of Swarthmore, completed an investigation of the distribution of bright B5-type stars, based on reclassification of available C and X

spectrum plates. The editorial work on the "Catalogue of Meteoritic Dust" was completed, and a classification made of approximately 90 spectra of early-type stars taken with the 60-inch (SQ series) telescope during the past year. Dr. Hoffleit hopes to continue work on sequences and variables in Milky Way Field 193 in Sagittarius.

Dr. Sergei Gaposchkin has published in Harvard Annals 113, No. 2, the detailed research on bright eclipsing variables, work initiated in 1938 with Dr. C. H. Payne-Gaposchkin. Dr. S. Gaposchkin spent three months at Mt. Wilson and Mt. Palomar Observatories, collaborating with Dr. Walter Baade in the exploration of brightness of more than two hundred variable stars in the Andromeda Nebula. This collaborative work continues. Also in collaboration with Dr. Baade are Dr. S. Gaposchkin's studies of the galactic "bulge," soon to be prepared for publication. During the coming year, Dr. S. Gaposchkin plans to continue his research in variables, Andromeda Nebula studies with Dr. W. Baade, some studies of individual stars suspected of variability, and the obtaining of color-magnitude diagrams of globular clusters.

During the last year, Dr. C. H. Payne-Gaposchkin has devoted her primary effort to the writing of three books on astronomy. "Stars in the Making," one of the Harvard Books on Astronomy, was published by the Harvard University Press in November 1952. It embodies the series of lectures sponsored by the Lowell Institute of Boston, and delivered in the fall of 1951, on "Stellar Evolution."

"Variable Stars and Galactic Structure," a technical monograph, is now in press at the Athlone Press, London University. It embodies the series of special lectures that Dr. C. H. Payne-Gaposchkin was invited to deliver at London University in the spring of 1952.

An elementary textbook of general astronomy will shortly be issued by Prentice-Hall, under the (probable) title: "Introduction to Astronomy."

During the spring semester, Dr. C. H. Payne-Gaposchkin acted as Chairman of the Department of Astronomy during Professor Whipple's sabbatical leave.

Dr. C. H. Payne-Gaposchkin was invited to participate in the conference on photoelectric photometry, sponsored by the

National Science Foundation, in September 1953, at the Lowell Observatory, Flagstaff, Arizona, and was in charge of the discussion on photoelectric observations of variable stars. She has been appointed the Chairman of the Subcommittee on the spectra of variable stars of the International Astronomical Union, and is engaged on the preliminary work of the report of this Subcommittee.

Also, Dr. C. H. Payne-Gaposchkin has been engaged in producing for the Observatory a modern collection of about three thousand lantern slides (2 x 2 inches). This project was financed by the Tozier Fund for Visual Education, and is nearly completed. Her current researches deal with the problems of the structure of galaxies, the spectra of novae (on which she has undertaken to write a monograph for the international series of astrophysical monographs sponsored by the astronomers of the Netherlands), and high-dispersion stellar spectra. A detailed study of the spectrum of Rigel, based on plates lent by the Mt. Wilson and Mt. Palomar Observatories, and supported by a grant from the Office of Naval Research, is almost completed.

During the past year, the publication of the ten-year survey of the brighter variable stars, undertaken by Dr. C. H. Payne-Gaposchkin and Dr. Sergei Gaposchkin under the sponsorship of the Milton Fund of Harvard University, was completed. The whole survey, which involved two thousand variable stars and included the discussion of more than two million measures, fills two volumes of the Harvard Annals.

Mrs. Margaret W. Mayall, Pickering Memorial Astronomer and Recorder for the American Association of Variable Star Observers (A. A. V. S. O.), continued to collect visual and photoelectric observations from A. A. V. S. O. members. These activities are plotted and show current activities of about 800 variable stars. Light curves and times of observed maxima and minima were supplied to many astronomers, including those at Mt. Wilson, Lick, and Yerkes Observatories. The Harvard Annals, Vol. 114, will contain such data, and also tables and plots of the mean light curves for about 400 long-period variables. Light curves of several semi-regular red variables have been compiled under a grant from the U. S. Office of Naval Research, and have been published in the Journal of the Royal Astronomical Society of Canada. The Bi-Monthly Predictions of Brightness

of Variable Stars and the Annual Predictions of Maxima and Minima of Long Period Variable Stars for 1953 have been issued.

We begin the year 1953–54 with enthusiasm and optimism. Renovations are under way for the machine and optics shops; working drawings for a new Building A are being prepared by the University architect and a structural engineer. The 15-inch telescope and rotunda will be kept. The rotunda will probably be used for astronomical exhibits. Several offices are being redecorated. The darkroom is to be renovated and a kitchenette installed on the first floor of Building D near the lecture hall. Dr. H. Bondi of Cambridge University, Cambridge, England is presently conducting a six-weeks seminar, and the regular series of colloquia will begin in October.

Donald H. Menzel
Acting Director

APPENDIX

I. Conferences

A. December 28–31, 1952, American Astronomical Society, Amherst, Massachusetts.

1. "A Search for Southern H-alpha Emission Regions" — Bart J. Bok, Michiel J. Bester, and Campbell M. Wade.
2. "AAVSO observations of AE Aquarii" — Margaret W. Mayall.
3. "Note on the Distance of the Magellanic Clouds" — Harlow Shapley.
4. "On the colors in five Constellations in the Large Magellanic Cloud" — Virginia McKibben Nail and Harlow Shapley.
5. "Calculated Line Profiles for the 21-cm Line of Hydrogen" — David S. Heeschen.
6. "Kinetic Temperature, Electron Temperature, and 'turbulence' in Stellar Atmospheres" — P. L. Bhatnagar, Max Krook, and Richard N. Thomas.
7. "On the Motions of 64-Long-period Comets" — Salah Hamid and Fred L. Whipple.
8. "The photographic Perseid Meteor Radiant" — Frances W. Wright.
9. "Magnetohydrodynamics of Aurorae" — Donald H. Menzel.
10. "Solar Limb Flares and the Yellow Coronal Line" — F. P. Dolder and W. O. Roberts.
11. "Preliminary Intensities of Balmer Lines from the Flash Spectrum at the 1952 Solar Eclipse" — R. G. Athay, D. E. Billings, J. W. Evans, and W. O. Roberts.
12. "Isophotal Contour Photometry of a Solar Flare" — D. E. Billings and W. O. Roberts.

B. June 22–27, 1953 — Groningen Symposium on Coordination of Galactic Research, Groningen, Holland. Attended by Bart J. Bok.

1. "Preliminary Results of a Southern H-alpha Survey" — Bart J. Bok, J. M. Bester, and C. M. Wade.

C. July 3–11, 1953 — Symposium on Gas Dynamics of Interstellar Matter, Cambridge, England. International Astronomical Union. Attended by Bart J. Bok, Donald H. Menzel, Richard N. Thomas.

1. "Photographic Studies of Southern Emission Nebulae" — Bart J. Bok.
2. "Remarks on the Constancy of the Ratio Between Gas and Dust in Interstellar Space" — Bart J. Bok.
3. "Magnetohydrodynamics of the Interstellar Medium" — Donald H. Menzel.

D. July 13–15, 1953. Symposium on Radio Astronomy, Manchester, England. Attended by Bart J. Bok and Priscilla Bok.

E. August 22–26, 1953. Joint Commission on High Altitude Research Stations. Donald H. Menzel, Chairman.

F. August 26–30, 1953. American Astronomical Society, Boulder, Colorado.

1. "Analysis of Balmer Continuum in the 1952 Eclipse" — Richard N. Thomas, D. Dimock, D. E. Billings, and R. G. Athay.
2. "Departures from Thermodynamic Self-absorption and the Balmer Line Spectrum from the 1952 Eclipse" — Richard N. Thomas, S. Matsushima, C. A. Whitney.
3. "Comment on the Progressive Wave in a Cepheid Atmosphere" — Richard N. Thomas and C. A. Whitney.
4. "Emission Line Corona and the Solar Activity Cycle" — Barbara Bell.
5. "Intensities in the Balmer lines and continuum at the 1952 eclipse" — R. G. Athay, D. E. Billings, J. W. Evans, and W. O. Roberts.
6. "A Magneto-hydrodynamic model of Solar Prominences" — Donald H. Menzel, Max Krook, Richard N. Thomas.
7. "Origin of white light coronal streamers" — W. O. Roberts, R. Grenchik, D. E. Billings.
8. "Recent Studies of Chromospheric Spicules" — J. H. Rush, W. O. Roberts.
9. "Evolution of coronal regions" — D. E. Billings, W. O. Roberts and D. H. Liebenberg.
10. "Nebulosities of the Small Magellanic Cloud" —Virginia McKibben Nail, C. A. Whitney, Campbell M. Wade.
11. "On the theoretical interpretation of Meteoric Spectra" — Allen F. Cook, II.
12. "On the Moment Method of Solution of Transfer Equations" — Max Krook.

13. "The Eclipsing Variable ZZ Bootis" — Sergei Gaposchkin.
14. "Nova Monocerotis 1942" — Sergei Gaposchkin.

G. August 31–September 1, 1953. Flagstaff Conference on Photoelectric Problems, Techniques, and Instrumentation, Flagstaff, Arizona. Dr. Cecilia Payne-Gaposchkin in charge of discussion on Intrinsic Variable Stars.

1. "Conditions for Photoelectric Research at the Boyden and Agassiz Stations of Harvard Observatory" — Bart J. Bok.
2. "Remarks on 'Seeing' as a Factor in the Selection of a Site for a Photoelectric Observatory" — Bart J. Bok.
3. "Size and Type of Telescope for a Photoelectric Observatory" — Bart J. Bok.

II. Publications for the Year 1952–53

A. The following regular publications have been issued during the year by the Observatory.

Annals:

Vol. 119, No. 2. "A Preliminary Survey of Nebulosities and Associated B-stars in Carina." By E. D. Hoffleit.

Vol. 113, No. 2. "The Eclipsing Variables" by S. Gaposchkin.

Quarterly Reports:

Nos. 12, 13, 16, 17. American Association of Variable Star Observers. Margaret W. Mayall, Recorder.

Announcement Cards:

Nos. 1191–1224. Report on comets, novae, asteroids, variable stars, etc.

Reprints:

Nos. 366–373.
Series II, Nos. 43–50.

B. The following Scientific and Technical Reports were issued during the year on government contracts for research work at the Observatory.

Contract AF19(604)–146

Scientific Report No. 4, September 30, 1952 (not previously reported) "Radio Observations of the Sun" — A. Edward Lilley.

S. R. No. 5, March 24, 1953 — "The Reduction of Measured Coronal Intensities to True Intensities" — James W. Warwick.

S. R. No. 6, May 22, 1953 — "On the Sources of Errors Affecting Observations and Measurements of Corona Line Intensities" — Dr. Ching-Sung Yü.

S. R. No. 7, May 22, 1953 — "A Nomographic Determination of the Latitude of a Point on the Sun's Limb" — John G. Wolbach.

S. R. No. 8, July 16, 1953 — " 'Turbulence,' Kinetic Temperature and Electron Temperature in Stellar Atmospheres" — P. L. Bhatnagar, M. Krook, D. H. Menzel, and R. N. Thomas.

S. R. No. 9, July 16, 1953 — "The Behavior and Classification of Solar Prominences" — Donald H. Menzel and John W. Evans.

S. R. No. 10, July 27, 1953 — "The Variation in Prominence Distribution Over the Sunspot Cycle" — Donald H. Menzel and Barbara Bell.

S. R. No. 11, September, 1953 — "A Kinetic Approach to Collision Processes in Gases" — P. L. Bhatnagar, E. P. Gross (M.I.T.), and Max Krook.

S. R. No. 12, September 30, 1953 — "Comparison of Annual Intensities of Coronal Emission Lines: Climax, Sacramento Peak, Arosa, Kanzelhöhe, Pic du Midi, Wendelstein." Barbara Bell and Harold Glazer.

Contract N50RI–07647

Technical Report No. 11, Harvard Reprint, Series II, No. 47 — "The Photographic Perseid Meteor Shower" — F. W. Wright and F. L. Whipple.

C. Publications by Observatory Staff Members during 1952–53.

BOK, B. J.

Three Weeks of Symposia, Sky and Telescope, Nov. and Dec. 1953.

Der südliche Spiralarm unserer Milchstrasse, with M. J. Bester and C. M. Wade, Physikalische Blätter, *9*, 245, 1953.

EVANS, J. W.

Preliminary intensities of Balmer Lines from the Flash Spectrum, with R. G. Athay, D. E. Billings, and W. O. Roberts, Abstract, The Astronomical Journal 58, 33, 1953.

FOWLER, F. E.

An Isophotal Contour Densitometer, with D. W. Johnson and D. E. Billings, Journal of the Optical Society of America, *43*, 63, 1953.

GAPOSCHKIN, C. H. P.

Stars in the Making. Harvard University Press, November, 1952.

HAMID, S. E. See F. L. Whipple.

HOFFLEIT, E. D.

A Bibliography on Meteoric Dust, with Brief Abstracts, Technical Note No. 9 (H. R. Series II–43), 1952.

News Notes, Sky and Telescope (about 80 items a year).

Note on the Distribution of B_5 Stars, with Sarah Lippincott, Astronomical Journal, *58*, 167, 1953.

The Origin of Chubb Crater, Journal of the Royal Astronomical Society of Canada, *47*, 126, 1953.

A Period for Arend's new Variable, Astronomical Journal, *58*, 168, 1953.

MAYALL, M. W.

Variable Star Notes, The Journal of the Royal Astronomical Society of Canada, *46*, 6; *47*, 1, 2, 3, 4.

MENZEL, D. H.

Flying Saucers, Harvard University Press, 1953.

Mathematical Physics, Prentice-Hall, Inc., 1953.

Why Flying Saucers Show Up On Radar, Look Magazine, September 1952. (Not previously reported)

NAIL, V. MC K. *See* H. Shapley.

ROBERTS, W. O.

Eruptive Prominences Associated with Limb Flare of May 8, 1951, with Thomas J. Bartlett and Bruno Witte, Astrophysical Journal, *117*, 292, 1953.

Isophotal Contour Photometer of a Solar Flare, with Donald E. Billings, Abstract, The Astronomical Journal, *58*, 35, 1953.

Solar Limb Flares and the Yellow Coronal Line, with Frederick P. Dolder, Abstract, The Astronomical Journal, *58*, 37, 1953.

SHAPLEY, H.

An Alphabet of the Universe. Gentry, No. 7, 1953.

The Distances of the Magellanic Clouds, Abstract, Astronomical Journal, *58*, 47, 1953.

Magellanic Clouds: V. Fifty Eclipsing Stars, with V. McK. Nail, Proceedings of the National Academy of Sciences, *39*, 1. (H. R. 368).

Magellanic Clouds: VI. Revised Distances and Luminosities, Proceedings of the National Academy of Sciences, *39*, 349. (H. R. 372).

Magellanic Clouds: VII. Star Colors and Luminosities in Five Constellations, with V. McK. Nail, Proceedings of the National Academy of Sciences, *39*, 358. (H. R. 373).

Note on the Distribution of RR Lyrae Variables. Astronomical Journal, *58*, 141. (H. R. Series II–50).

On Colors in Five Magellanic Cloud Constellations, with V. McK. Nail, Abstract, Astronomical Journal, *58*, 45. The Rumford Bicentenary, Proceedings of the American Academy of Arts and Sciences, *82*, No. 7, 1953.

WHIPPLE, F. L.

On the Motions of 64 Long-Period Comets, with S. E. Hamid, Astronomical Journal, *58*, 100–108, 1953 (H. R. Series II, 48). On the Icy Conglomerate Comet Model, La Physique des Comets, p. 281, Liege, Belgium.

The Photographic Perseid Meteor Showers, with F. W. Wright, Harvard Technical Report No. 11, (H. R. Series II, 47).

WRIGHT, F. W. *See* F. L. Whipple.

D. *Publications in Press.*

BOK, B. J.

Milky Way Structure in Sagittarius and Carina, Vistas in Astronomy, Pergamon Press Ltd., London, England.

C. H. PAYNE-GAPOSCHKIN

Variable Stars and Galactic Structure, Athlone Press, London University, London, England.

Introduction to Astronomy, Prentice-Hall, Inc.

D. H. MENZEL

Fundamental Formulas of Mathematical Physics, Prentice-Hall, Inc. D. H. Menzel, Editor.

"Turbulence," Kinetic Temperature and Electron Temperature in Stellar Atmospheres, with P. L. Bhatnagar, M. Krook, and R. N. Thomas, Vistas in Astronomy, Pergamon Press Ltd., London, England.

The Behavior and Classification of Solar Prominences, with John W. Evans, Proceedings of the Convegna Volta, Italy.

H. SHAPLEY

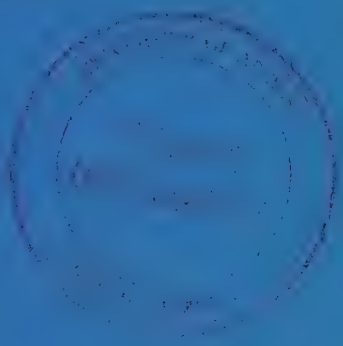
The Expanding Universe, Gentry, No. 8, 1953.
Life-Bearing Planets, Atlantic Monthly, *191*, 29.
Measures of our Galaxy and Others. Irish Astronomical Journal.
A Test for High Altitude Absorption as a Factor in the Distribution of Galaxies, Publications of the Astronomical Society of the Pacific, *65*, 386.
Note on the Light Variations of Proxima Centauri. Astronomical Journal.
Magellanic Clouds: VIII. On the Population Characteristics of the Two Clouds. Proceedings of the National Academy of Sciences.
Tables for Cosmography. University of Mexico Press.

R. N. THOMAS

The Physical Theory of Meteors IV. Inquiry into the Radiation Problem — a Laboratory Model, with W. C. White of the Naval Ordinance Test Station.
Also, see D. H. Menzel.

HARVARD
ASTRONOMICAL OBSERVATORY

ANNUAL REPORT



1954

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Harvard College Observatory

To the Dean of the Faculty of Arts and Sciences:

Sir, — I am pleased to submit this annual report on the behalf of and with the advice of the Harvard College Observatory Council, consisting of Professor Bart J. Bok, Dr. Cecilia Payne-Gaposchkin, Professor Fred L. Whipple, Dr. Richard N. Thomas, Dr. Gerhard R. Miczaika, and myself, Donald H. Menzel, Chairman. The report covers the activities of the Observatory and its associated stations during the year 1953–54. During this period I served as Acting Director until February 1, 1954. Since that time I have served as Director. During the year, Drs. Thomas and Miczaika were appointed to the Council.

With reference to the physical plant in Cambridge, the plans for rehabilitation and modernization, outlined in my report last year, have largely been completed. The new building A, which replaced the old wooden structure, is now complete and occupied. The building contains 24 new offices, a storage room, a file room, a room for utilities, a room especially designed for conferences and small classes, a new classroom for 50 students, and lavatory facilities.

The reassignment of offices permits much more effective use of the older quarters. During the spring the American Association of Variable Star Observers moved its headquarters from the old building A to offices at Harvard Square.

During the year several small wooden sheds were razed, including one that once housed the old 60-inch reflector. The "residence," occupied by former directors, was adjudged not worth saving, and, accordingly, has been torn down. The foundation has been filled in and the grounds are being currently landscaped. The driveway to the residence will be enlarged to provide a badly needed parking lot.

A large metal shed, previously used for storage, was fully renovated to provide an optical shop, a machine shop, and a small carpenter shop. The optical shop has been made available to the Amateur Telescope Makers of Boston, and their presence has contributed significantly to the Observatory activity, as will be noted later in this report. The old machine shop, long condemned, is scheduled for early demolition.

Renovation of the older offices has continued. Although a few rooms are still untouched, the most urgent renovation is nearing completion, except for the Rotunda, under the 15-inch telescope, the so-called "Prime Vertical" room, and the passageway from building C to A. Tentative plans call for conversion of the foregoing areas into space for exhibition of astronomical photographs and astronomical techniques, for use in student training and for demonstration to the public. The Rotunda, which previously served as library stacks, contains a 16-sided wooden structure surrounding the stone pier that goes through the center of the room to support the 15-inch telescope above. The old book cases on this inner wall can be readily converted to hold transparencies of astronomical photographs, with illumination from the rear. Four alcoves in the room provide space for additional exhibits. We have received a grant of $1000 from the Tozier fund, to defray part of the expenses of preparing the exhibits.

In building D, the renovation has included the installation of adequate lighting in the library, and the complete renovation of the old darkroom, including installation of a modern stainless steel photographic sink. The modernization of the darkroom was undertaken with the advice of experts from the Eastman Kodak Laboratories.

The old 15-inch telescope, 111 years old, is being completely reconditioned. Removal of many coatings of paint and dirt reveals a beautiful instrument, of brass and fine mahogany. We are endeavoring to restore the telescope to its original appearance. The interior of the dome has been repaired and painted.

The floor, which is in bad condition, will eventually be covered with linoleum tile.

For the time being, we shall use the original lens. However, within the next two years, we hope to replace the old lens by a completely new optical system of the Schupmann type. This lens system, designed for us by our Research Associate, Dr. James G. Baker, is fully corrected for color. In other words, all of the rays, irrespective of color, come to precisely the same focus. This lens system was made for the Observatory. Mr. James Gagan, one of the skilled members of the Amateur Telescope Makers of Boston, made the components of the optical system in our optical shop and presented them to the Observatory. The total cost of the device was far below its actual value. The system is now in temporary use on the big coronagraph, at Sacramento Peak, New Mexico, where Mr. Gagan went to install it. The performance appears to be excellent. When we finally transfer the lens to Cambridge, the 15-inch telescope will become one of the most modern instruments of its size in the world.

The clock drive of the telescope, which had undergone substantial alteration during the lifetime of the instrument, has long since been completely outmoded. We have discarded it and are replacing it by a modern electronic drive, whose speed can be adapted to follow the sun or moon as well as the stars. Since the telescope has never possessed a clamp or drive in declination, these are now being added. When the telescope is used for solar work, in combination with the Schupmann and a narrow-band birefringent filter, the electronic drive will be easily adapted to fully automatic following.

With the idea of strengthening our work in observational astronomy and making further improvements to the equipment, we have made two new appointments. Dr. G. R. Miczaika, Lecturer in Astronomy, has also been appointed Astronomer-in-Charge of the George R. Agassiz Station. Dr. William Sinton, a scientist particularly skilled in observational

techniques, is working with Dr. Miczaika on the problem of basic instrumentation.

The Observatory Council, acting on the recommendation of leading astronomers, invited Dr. Nicholas U. Mayall, Astronomer of the Lick Observatory, and Mr. William Baustian, chief engineer in charge of construction of the 120-inch reflector at Lick Observatory and one of the engineers responsible for the development of the 200-inch reflector at Palomar, to visit Cambridge and advise us on instrumental problems.

A careful examination showed that some of the equipment at the Agassiz Station should be improved to meet modern requirements of astrophysical research and training of graduate students in this field. The instruments in question are particularly the 8-inch camera, the 24-inch reflector, and the 61-inch reflector. Consequently, engineering work on the details of the rehabilitation work of these instruments has been initiated.

The 8-inch camera, which is almost exclusively of educational value, has already been rehabilitated by Mr. Anderson and Mr. Heighton.

The plans for the 24-inch reflector include provision for the use of the Cassegrain focus, a new drive of the electronic oscillator type, new motions in right ascension and declination, and a hemispherical dome to replace the present sliding roof. A new photoelectric photometer will be built in the shop of the Yerkes Observatory. Work on the improvement of the telescope has just been started, and it is hoped that the 24-inch and its housing will be fully rehabilitated by next spring. The rehabilitation of the 61-inch reflector is currently undergoing the process of engineering design. The general scheme includes a new electronic drive, new motions in both coordinates (guide, set and fast motion), a new mirror cell, better facilities for remote control, servos to indicate the setting, a new gear for fast motion in right ascension, provisions for use of the Cassegrain focus, improvement of the platform, and a modern aluminizing tank.

Plans for the 61-inch also include important accessory equipment, such as a modern grating spectrograph with several cameras and a series of dispersions between 15 and 200A/mm. Shop work for the new parts of the 61-inch will be started around the end of the year. Improvements for the Agassiz Station included the installation of an automatic time service consisting of a master-clock, automatically controlled by time signals from WWV, and a number of slaves in various buildings. It was a gift from Mr. Thomas J. Watson, Jr., of International Business Machines, Inc. Efforts have been made to reduce the humidity in the plate-storage room. Acting on recommendations by Dr. Mayall and Mr. Baustian, we have planned either to retire other telescopes, or to use them sparingly. The schedule for this retirement has not been completely worked out at the present time.

During the current year, studies in radio astronomy have comprised a significant part of the work at the Agassiz Station. This work will be described in detail later on in this report.

Dr. Bruno Rossi, Professor of Physics at the Massachusetts Institute of Technology, has required special research facilities for the study of cosmic-ray showers. A survey indicated that the Agassiz Station would be ideal for the purpose. Hence the Council has made the site available to Dr. Rossi for these studies. The aim of the work is the determination of the extent of the area over which the disintegration fragments of a single high-energy particle may extend. The shower consists of atomic fragments produced high in the earth's atmosphere.

To aid in the development of new instrumental techniques, to give additional training to students, and to provide basic facilities for special researches, we have just put into operation two laboratories in Cambridge, one for electronics and the other for optical studies. An excellent quartz spectrograph, on long-term loan from Dr. Marion Eppley, has been installed. Some minor work on the microdensitometer, particularly installation of the electronic units in a rack has been made dur-

ing the summer. Further mechanical improvements are in the planning stage.

The Harvard Observatory Council, charged with the problem of finding a satisfactory solution for the future of the Boyden Station, has continued to operate the Station on a limited budget for the current year.

Mr. Henry J. Smith remained at Boyden Station as Acting Superintendent until June 30, 1954, when Dr. Eric M. Lindsay, who came as the observer from Armagh Observatory, N. Ireland, assumed the position on a temporary basis and without charge to the Harvard budget. Mrs. Elske van P. Smith and Mr. T. Houck, who had been at Boyden Station since the beginning of the period covered by the present report, left to return to the United States also on June 30, 1954. The resident staff continues to be Mr. E. G. Burton, our mechanic, and Mr. M. J. Bester, our chief assistant.

The researches at Boyden Station have been largely in the nature of rounding off of research programs that had been initiated before the Corporation decision of January 1953 to discontinue full-time operation of Boyden Station under exclusive Harvard auspices. The first section of the Boyden Station Catalogue of Southern Emission Nebulae is now at the printer and valuable results with regard to association of interstellar gas and dust have been obtained as a result of this study. The joint program of photography in blue and red of the Southern Milky Way, with the aid of the Armagh-Dunsink-Harvard telescope of Baker-Schmidt design, is well underway and the Armagh and Harvard observers are giving top-priority to the completion of this joint project. The mirror of the ADH telescope was silvered twice during the course of the past year. The programs for spectral classification and the measurement of colors of selected southern stars of early spectral type have been completed and the data are now being analyzed by Dr. Hoffleit. Mr. Smith completed his spectral program for southern Wolf-Rayet stars and also a program for P Cygni stars in the Magellanic Clouds. Mrs. Smith col-

lected the thesis material for polarization studies of stars in the southern Milky Way; the 13-inch Boyden Refractor proved to be an exceedingly useful instrument for this research. Mr. and Mrs. Smith together completed a survey of southern infrared spectra for a belt centered upon the Milky Way. Good progress was made toward the completion of the Magellanic Cloud programs of Dr. Shapley and associates and of Dr. and Mrs. Gaposchkin. One new program was initiated for the 60-inch Rockefeller Reflector, a photometric study of southern spirals by Dr. C. P. Gaposchkin.

Professor G. G. Cillie, Jr. of the University of Stellenbosch was again a guest observer at Boyden Station. Mr. Houck, who was one of our assistants in the course of the year, spent a fraction of his time working on projects of interest to his home observatory of the University of Wisconsin. His researches dealt primarily with photoelectric and spectroscopic studies of southern stars of early spectral class, for which he used the 60-inch reflector as well as the ADH telescope with objective prism.

With two exceptions, we have provided no more than routine maintenance of buildings and equipment. The replacement of the wooden floor of the ADH building by a cement floor was completed in October, 1954, prior to the first silvering of the primary mirror. The second major improvement was the rebuilding of the dark room.

The present budgetary limitations at Boyden Station are severe, but these have been lightened considerably by gifts from the South African group of the Friends of Boyden Station.

The Boyden Station continued to attract many visitors. Dr. R. H. Stoy, Her Majesty's Astronomer at the Cape of Good Hope, Dr. W. H. van de Bos, Union Astronomer of S. Africa, and Dr. E. C. Slipher of Lowell Observatory, were among the astronomical visitors. The Prime Minister of the Union of South Africa, Dr. Daniel F. Malan, was the leading non-astronomer to visit the Station. In June, 1954, Boyden

Station was host to the S. African Association for the Advancement of Science.

Considerable interest has been shown in the future of the Boyden Station by various European observatories. In addition, the executive committee of the International Astronomical Union has expressed its concern lest an important observing station in the southern hemisphere be lost entirely to astronomy. Professor Menzel arranged with European astronomers for a joint conference to be held at the Hamburg Observatory, in Bergedorf, Germany, on 19 August, 1954. The following representatives attended: Dr. H. A. Bruck, of Dunsink Observatory, Southern Ireland; Dr. Otto Heckmann, Hamburg Observatory, Bergedorf, Germany; Professor Donald Menzel, Harvard Observatory, U.S.A.; Dr. Bertil Lindblad, Stockholm Observatory, Saltsjobaden, Sweden; Dr. Paul Bourgeois, Uccle Observatory, Brussels, Belgium. Dr. Eric Lindsay, Armagh Observatory, Northern Ireland, was unable to attend but Dr. Bruck acted as his informal representative. Dr. Lindsay has since approved the minutes of the meeting.

I shall not give all of the details of the provisional plans, which still require ratification of various governmental and university authorities. In brief outline, I should mention that plan A involves the cooperative use of the Baker-Schmidt reflector, commonly known as the ADH (Armagh-Dunsink-Harvard) telescope, provision for whose operation was made the subject of an agreement between the three sponsoring institutions in 1947. With Harvard withdrawing from active sponsorship of the Boyden Station, the new agreement, known as plan A, involves equal division of telescope time between all six observatories, with the major costs of operation defrayed by the three new members of the group, Hamburg-Stockholm-Uccle, with contributions by Armagh and Dunsink, toward the travel expenses and salaries of their observers. The foregoing institutions are to provide observers for a period of two years, with Harvard responsible only for the expenses of photographic plates used on its program.

Running concurrently with plan A, but involving the Harvard 60-inch reflector instead of the ADH, is a cooperative agreement between four observatories, Hamburg, Harvard, Stockholm, and Uccle. Here again, this two-year plan designated as plan B, requires no basic expenditure by Harvard other than for photographic materials. The expenses of observers and fundamental operation are to be borne by the other observatories. In brief, Harvard's original investment is regarded as sufficient justification for receiving a proportionate share of observing time.

The two foregoing plans run for two years, but they are subject to a further extension, plan C, conditional upon further mutual agreement between the six participating observatories. The Harvard Observatory Council believes that this plan is advantageous to astronomy in general and at the same time provides Harvard astronomers with important observing facilities in the southern hemisphere, facilities needed for a well-rounded research program.

The foregoing proposal has already received the ratification of several of the participants and the strong endorsement of the Friends of the Boyden Station in South Africa. The Council sincerely hopes that the interim plans will eventually crystallize into a stable, long-range plan for future cooperation between the aforementioned observatories.

Professor Harlow Shapley reports for himself and his assistants. The leading research projects of the group that is investigating galaxies and faint variable stars have been the delineation of the borders of the southern Milky Way, the investigation of the tilt of the "bar" of the Large Magellanic Cloud, and continued work on the census of the Inner Metagalaxy.

Four hundred long-exposure plates made with the Bruce telescope of the Boyden Station, supplemented by some photographs with the ADH reflector, have provided data on the distribution of faint galaxies between longitudes 200° and 240° and latitudes $-30°$ to $+30°$. The principal object of

the research is the determination of the extent and opacity of the dust clouds in low galactic latitudes. A preliminary report on the work was made at a Conference on "Solid Particles in Astronomical Objects" at Liege, Belgium, in July, 1954.

The study of cepheid variable stars in the Large Magellanic Cloud has brought to light a third anomaly in the distribution of periods. The concentration of the longer periods at the western end of the bar may bear on the evolutionary history of this irregular galaxy. The census of the Inner Metagalaxy is essentially complete and a monographic presentation of the work of the past twenty years is under preparation. The low galactic population in the area of the south celestial pole is now attributed mainly to space absorption, although large irregularities in metagalactic population are verified in the course of this study of the distribution of some 500,000 systems.

Smaller investigations include the examination of the flare characteristics of Proxima Centauri; discovery of new variable stars in Centaurus, including several in a low galactic region that is shown to be transparent by the presence of many galaxies; the finding of several hitherto unrecorded faint star clusters and planetaries in the southern Milky Way; the cataloging and spectrum analysis of nebulosities in the Small Magellanic Cloud; a collaboration with the Observatory of the University of Michigan in the survey of novae in the Magellanic Clouds; and the study of the population characteristics of the two Clouds of Magellan which apparently proves them to be similar in their content of supergiant stars of many kinds and essentially equally distant.

The corrections to the distance scale of external galaxies has been evaluated with the measurement of the magnitudes of the giant stars in those clusters of the Magellanic Clouds that on the basis of color and spectrum can be safely assigned to the globular category. A factor of 2.1 ± 0.2 is derived. This method will provide a more satisfactory value when improved magnitude standards become available.

Mrs. Virginia McK. Nail has been chief assistant in studies of the Magellanic Clouds, Miss Ann B. Hearn in the work on galaxy distribution, Miss Jacqueline Sweeney in observations with the Schmidt telescope at the Agassiz Station. In July Miss Hearn resigned and Pedro Kokaras joined the staff to assist in work on variable stars in Centaurus and on the Milky Way border project. An anonymous gift has covered much of the expense of the research on the anti-center Milky Way.

A full description of Professor Shapley's course of lectures in the Department of General Education, "Cosmography — An Approach to Orientation," has been published in the summer issue of American Scientist.

I noted in last year's Report that the period of construction of the new Radio Telescope at Agassiz Station was coming to a close. Full-scale operation began in December 1953 and several research projects have already been completed during the past ten months. Two doctoral theses are essentially written and the observations for two additional theses are nearing completion. Two non-doctoral projects round out the present research program. Among the most interesting research results obtained to date are the finding that neutral hydrogen gas is denser in regions where clouds of small solid particles exist. Also, of significance, is information concerning the distribution of neutral hydrogen in the central parts of our Milky Way System. The present research deals with the spiral structure of a section of the Milky Way and with studies of the distribution of neutral hydrogen in the section of the Nebula of Orion. Tests were made for the detection of radiation from the OH molecule, but the results of these were negative.

The Agassiz Station Radio Astronomy Project is under the joint direction of Bart J. Bok and Harold I. Ewen. Mr. John A. Campbell is now our full-time electronic engineer. The dual aim of the Radio Astronomy Project since its initiation has been to provide research results of value and to train graduate students for doctorates in the field. David S. Heeschen and A. Edward Lilley have completed their thesis projects and are

now engaged in teaching and research elsewhere. Thomas A. Matthews, T. K. Menon and Campbell M. Wade are the three graduate students on the Project at the time the present report is being written. To further the graduate training in the field two graduate courses related to Radio Astronomy are now being offered, one a course in Radio Astronomy, which surveys the whole field, the other a course in Interstellar Matter; Bart J. Bok and Harold I. Ewen have shared the first course, whereas Guido Munch of the California Institute of Technology is Bok's co-lecturer in this year's new course in Interstellar Matter. The installation at the Agassiz Station has been visited by many astronomers, physicists and electronic engineers from the United States and abroad.

The Radio Astronomy group took part in three symposia. The Symposium on Radio Astronomy held at the December, 1953, meeting in Boston of the American Association for the Advancement of Science was organized by Bok and associates; Ewen and Lilley reported on the work at the Agassiz Station. The second Symposium was held in Washington D. C. in January, 1954, under the auspices of the National Science Foundation; Bok and Ewen spoke at this Symposium. In addition Bok presented a paper *in absentia* at the Sixth International Astrophysical Symposium in Liege (Belgium), concerning the relationship of radio observations at Agassiz Station to the problem of the relative concentration of gas and dust in interstellar space. Ewen attended the meeting of the International Union for Scientific Radio (URSI) in The Hague (Holland) during August, 1954, and presented at these meetings the results obtained by the Agassiz Station Radio Astronomy Project.

The Project has been operated with support from the National Science Foundation and through gifts from an anonymous friend of the George R. Agassiz Station. Early this year, this same friend gave $25,000 toward the construction of Mobile Unit with electronic apparatus of improved design for the recording of the hydrogen radio radiation from interstellar space; an additional grant of $8,000 for the same pur-

pose was received from the Research Corporation. The design and construction of the Mobile Unit is in the hands of Dr. Harold I. Ewen, who also constructed the Unit now in use at Agassiz Station.

Our greatest need for the future is for a larger parabolic dish or equivalent antenna array to receive the radio radiations from space. At the moment, our electronic recording apparatus is capable of yielding information of more detailed character than our 24-foot antenna can supply. A whole new array of astronomical problems would present itself if we were to use the electronic equipment available and under construction in connection with a parabolic antenna of 60 to 80 feet in diameter. The Council hopes that provision for such an antenna can be made in the near future.

The Meteor Projects, under the direction of Dr. F. L. Whipple, have continued at a high-level peak of activity during the course of this year. The observing program supported by the U. S. Office of Naval Research and by the U. S. Air Force utilized its full component of four Baker-Super-Schmidt Meteor Cameras and various auxiliary equipment at the two stations near Las Cruces, New Mexico. When Dr. William Liller left the Project in June, 1953, to accept a position at the University of Michigan, Mr. Samuel B. Whidden took over the immediate supervision of the stations. Some 1330 meteors have been photographed during the course of the year, and over a dozen well-defined persistent meteor trains multiply photographed at one or both stations.

Dr. Allan Cook and Mr. Robert Hughes, with the assistance of Mr. Richard Southworth and Mr. John Murphy, have conducted analyses of the wind motions measurable on these photographs.

Dr. Allan Cook, in a collaborative effort with the Dominion Observatory at Ottawa, Canada, discovered the first evidence of atmospheric components in meteor spectra, nitrogen bands, and verified the presence of hydrogen in the spectrum of a fast meteor. He has further analyzed and investigated the

nature of the meteoric phenomenon with substantial progress in his understanding.

Dr. Whipple has continued in his studies of the origin of the Zodiacal Light as related to cometary debris, the origin of meteorites and photographic meteors, and further studies of winds in the high atmosphere. His basic paper on 144 photographic meteor orbits published this year clarified a number of long-standing questions concerning the space motions and origins of meteors.

Mr. Robert Hughes has continued his study of compressible fluid dynamics in the high atmosphere.

Mr. Richard E. McCrosky's doctoral research on the "wake" phenomenon in meteors is progressing well. He finds that the short-lived persistence of meteoric radiation most probably arises from fragmentation.

Miss Frances W. Wright continues her studies of the intrinsic scatter and motions in the radiants of photographic meteor showers. A newly-discovered relationship between the inherent scatter of individual meteors from the mean radiant point and the total duration of the individual shower suggest that the processes of particle distribution in meteoric streams are rather uniform in character independently of the shape or size of the orbit.

Dr. Salah Hamid, who has returned from Egypt to work with the Projects for a year, has made an intensive study of the perturbing forces influencing the orbits of the Geminid meteor shower. He has further continued the analysis begun by Dr. Whipple of the origin of the zodiacal cloud.

Plans for the future of the observing program were altered by the withdrawal of the Office of Naval Research from direct support of the meteor-observing program in New Mexico. This change and other circumstances required that the stations be moved to more permanent sites with commercial power facilities. Through the courtesy of the Air Force Solar Project at Sacramento Peak, one station has been located at this position, and the second one in Mayhill, New Mexico, some

22 miles northeast. The observing program will be supported entirely by the Air Force during the following year. The relocation was initiated in July, and the cameras were expected to be back in operation during October, 1954.

A low-dispersion objective grating of the replica transmission type has been ordered for use with one of the Super-Schmidt Meteor Cameras, and delivery is anticipated during the winter. We anticipate that this new grating will give us, for the first time, a statistical insight into the type of radiation produced by the meteoric phenomenon. A program with fast small Schmidt cameras equipped with objective gratings has not yet led to the direct photography of the spectrum produced by a persistent meteor train. The grating for the Super-Schmidt Camera may make this feat possible; we still remain in ignorance concerning the nature of the light so produced.

Four members of the Meteor Project, Dr. Cook, Dr. Jacchia, Dr. Thomas, and Dr. Whipple attended the extremely valuable conference on the physics of the meteoric process held at the Jodrell Bank Experimental Station of the University of Manchester, England, in July, 1954. The conference was both instructive and inspirational. Research workers in the field of meteors from all sections of the globe were present.

The emphasis in the research supported by the Office of Naval Research for the coming year will be changed to the wholesale taxonomic analysis of the data obtained in New Mexico by the Baker-Super-Schmidt Cameras. Mr. Richard E. McCrosky initiated one of the two methods of approximate analysis during the summer of 1954.

The Meteor Analysis Project under the direction of Dr. F. L. Whipple and Dr. Luigi Jacchia has continued its reductions of meteor photographs taken with the Super-Schmidt Cameras in New Mexico, with the support of the U. S. Army Office of Ordnance Research.

A comparative analysis of all the available Super-Schmidt material, covering mostly faint meteors (visual magnitudes

from 0 to 3) and of the meteor photographs previously taken with the aid of smaller cameras (visual magnitudes brighter than zero) revealed a striking difference in behavior between bright and faint meteors, especially in the manner in which they decelerate in the atmosphere. Dr. Jacchia successfully explains this discrepancy by assuming a progressive fragmentation of meteors in the course of their trajectories. He presented this theory at the June meetings of the American Astronomical Society and at the conference on meteor physics at the Jodrell Bank Experimental Station of the University of Manchester, England, in July.

Orbital results for the Delta Aquarid meteor shower have been presented, in a paper by F. W. Wright, L. G. Jacchia, and F. L. Whipple, at the December meeting of the American Astronomical Society (none of the authors attended). Work is in progress on the Iota Aquarid and Alpha Capricornid streams.

An analysis of the meteor-deceleration material to detect evidence of solar and lunar tides in the upper atmosphere led to rather inconclusive results early last spring. Since then much new observational material makes it possible to correct the atmospheric densities from meteors for the effects of fragmentation so that the analysis can be resumed.

During the summer months Dr. S. Hamid devoted some time to adapting part of the meteor reductions to automatic computation with punched-card machines. By October 1, International Business Machines Corporation machines at the Massachusetts Institute of Technology Center of Analysis will carry out most of the routine computations involved in the reductions.

Dr. Richard N. Thomas has continued his work in astroballistics, particularly on those aspects relating to the correlation of meteor studies with ballistic experiments on artificial meteors. The applications of some of the more modern methods in physical chemistry to rate-processes occurring in astroballistics, commenced by Thomas in collaboration with a

group from the University of Utah, continues. These applications include: (1) a study of the luminosity problem by R. N. Thomas and W. C. White (Ap.J., *118*, 555, 1954); (2) an application of the Cook-Eyring-Thomas model of the meteoric ablation process to the first stages of the meteor path by A. F. Cook (Ap.J. in press); (3) collaboration with a Utah group, under M. E. van Valkenburg, studying ionization produced by artificial meteors. These astroballistic investigations, together with those from "shock-tube" work, provide the only available laboratory studies of ultra-speed aerodynamical processes akin to those occurring in stellar atmospheres. The close relation of our researches in meteors, the sun, and variable stars, through their common aerodynamic problems, provides a strongly unifying factor in the planning of our general observatory program.

The following people have worked on the Meteor Project in Cambridge during the past year: Professor Fred L. Whipple, Miss Frances W. Wright, Dr. Allan F. Cook, Dr. Salah E. Hamid, Mr. Robert Hughes, Mr. Fred Franklin, Mr. William Tifft, Mr. W. R. Angell, Mrs. Mary B. DeVeber, Miss Lillian C. Battle, Dr. Luigi G. Jacchia, Mr. Robert Briggs, Miss J. R. B. Carmichael, Mr. Richard E. McCrosky, Miss Elaine M. Guinee, Miss Belle J. Helpern, Miss Constance Kemball, Miss Barbara Litman, Mr. John Murphy, Mrs. Martha Shapley, Mr. Richard Southworth, Mrs. June Wessel, and Mr. G. F. Davoren.

In New Mexico the following people have been employed on the Project during the year: Mr. Samuel Whidden, Mr. Gunther Schwartz, Mr. Arthur Partridge, Mr. Joe L. Coultis, Mr. Edward Horine, Mr. Kenneth Morrison, Mr. J. Harry Emerson, Mrs. Dorothy Zimmermann, Mrs. Doris Williams, Mrs. Virginia Schwartz, and other employees in capacities of plate molders and film inspectors.

In December, 1953 Dr. Cecilia Payne-Gaposchkin received the honorary degree of Sc.D. from Western College for Women. During the past year she has discussed and prepared

for publication the observations of Cepheid variables, RR Lyrae stars, long-period variables and semiregular variables, made under a grant from the Milton fund during the past decade. These results are about to appear in Volume 113 of the Harvard Annals.

She has published an elementary textbook of astronomy, entitled "Introduction to Astronomy." The technical monograph entitled "Variable Stars and Galactic Structure," which embodies the Special Lectures delivered by Mrs. Gaposchkin at London University in 1952, has been completed and is about to appear.

She has engaged in the analysis of a number of Coudé spectra of Beta Orionis, lent by Mount Wilson Observatory, and has completed the first of two papers describing the investigation, which was supported by a grant from the Office of Naval Research.

She has analyzed the spectrum of the rotating star Beta Cassiopeiae, lent by the McDonald Observatory, and made a detailed comparison with the spectrum of Procyon in selected wavelengths.

She has analyzed the spectrum of Epsilon Orionis, lent by the McDonald Observatory, and she is continuing the study of the spectra of several A and F stars, also lent by the McDonald Observatory.

As a delegate to the Rydberg Conference in Lund Dr. Gaposchkin visited Sweden and contributed an invited paper on the spectra of rotating stars. She also visited the Observatories at Bergedorf and Gottingen.

For a number of years, one of the chief aims of the Harvard solar program has been the promotion and development of unique laboratory and instrumental facilities for study of the sun and of solar-terrestrial relationships. With the completion of the major portion of the facilities at the two main western observing stations, we now expect the emphasis to shift from instrumentation to a combination of observation, analysis, and theoretical research.

During the current year, the first of the new set of research instruments went into operation at the Upper Air Research Observatory (UARO), on Sacramento Peak, New Mexico, to supplement the systematic coronal survey program currently maintained there by Harvard College Observatory (HCO). In September, the High Altitude Observatory (HAO) of Harvard University and University of Colorado dedicated their new observatory at Climax, Colorado, simultaneously with the dedication of the new building of the Central Radio Propagation Laboratory (CRPL) of the National Bureau of Standards, in Boulder, Colorado. At some phase, each of these three scientific organizations, UARO, HAO, and CRPL, have had close association with the Harvard solar program. For administrative reasons, it has become necessary to dissolve the official connection between HCO and HAO, although our common, cooperative research program has attained new high levels.

In May, Dr. Menzel delegated to Dr. Richard N. Thomas, the day-to-day direction of the Harvard solar program. Dr. Thomas, prior to coming to Harvard, was a vigorous participant in the western solar program. For all of these reasons, the institution of a broad, informal, working arrangement between the four institutions (UARO, HAO, CRPL, HCO) became the next natural step in the evolution of our solar program.

In June, a conference was held in Boulder, Colorado, between Dr. John W. Evans, Director of UARO; Dr. Walter O. Roberts, Director of HAO; Mr. A. H. Shapley, representing CRPL; Dr. Richard N. Thomas, for the Harvard solar program, with Professor Donald H. Menzel acting as chairman. The discussion centered chiefly on ways and means for coordinating the overlapping phases of the scientific solar program. To give a semblance of unity to the objectives of the conference, the five representatives agreed to comprise a body known informally as the "Solar Associates." The immediate discussion concerned the development of joint scientific programs, the interchange of personnel, and the use of

the facilities of each institution to provide a more effective graduate program in solar astrophysics and solar-terrestrial relations.

The interchange of personnel began immediately with the following assignments: Dr. Barbara Bell from Harvard to CRPL for five months; Mr. Frank Q. Orrall and Dr. Harold Zirin from HCO to UARO for six months; Drs. James and Constance Warwick from UARO to HCO for six months; Professor Menzel and Dr. Thomas from HCO to UARO and HAO for the summer months; Mr. Robert Lawrence from CRPL to HCO for six months. A further extension of this program is planned for the coming year.

In this way, the overall Harvard solar program, with its gradually changing objectives, fulfills a multitude of purposes, ranging from basic scientific research to the training of scientists within the framework of a strong graduate school. Our research program is expanding, with new phases and applications appearing daily. Here at Harvard we plan to concentrate on analytical and theoretical aspects, with emphasis on personnel rather than on instrumentation. The solar program parallels those of meteor and radio astronomy, in the development and application of cross-field relations between astrophysics, atomic physics, aerodynamics, meteorology, and atmospheric geophysics. A current wide demand exists for personnel with broad backgrounds in the foregoing cross-field areas — a demand that far exceeds the supply. One of our aims is the training of students for work in these important areas.

Our responsibility toward the Upper Air Research Observatory on Sacramento Peak continues, partly in the management of the systematic survey program, and partly through the provision of theoretical and analytical guidance. Mr. Harry Ramsey continues as Observer-in-Charge of our survey program, assisted by Mr. George Schnable, Mr. Howard de Mastus, and Mr. Edward H. Bergstrom. Dr. Ching-Sung Yü has maintained his intercomparison of the Climax and

Sacramento Peak data, and has been working on the problem of improving the film standardization. Mr. Richard B. Dunn has been working with the above-mentioned observers in devising a more complete coverage, in time and position on the sun, of our coronal-line, prominence, and flare surveys.

Dr. Barbara Bell, Mr. Harold Glazer, and Mr. John Wolbach have continued their study of the data from this survey program to investigate correlations between coronal line emission and geomagnetic effects. They find a tendency for strong coronal line emission to be associated with low geomagnetic activity, and conversely. On the supposition that geomagnetic activity roughly measures the solar corpuscular emission that reaches the earth, they suggest that bright coronal areas tend to inhibit the escape of corpuscular emission from the sun. The subject is of the greatest importance in basic communication and meteorological research. A series of discussions on this subject was held during the summer at the CRPL, in which Dr. Bell joined with Dr. Roberts from HAO in advisory capacity to the CRPL program under Mr. Alan Shapley.

Dr. James Warwick and Dr. Constance Warwick have carried out extensive studies of the solar flares, from the observations maintained continuously over the last three years. From a study of the association between limb-flares and ionospheric disturbances, they find strong evidence to support the idea that radiation from the Lyman, rather than the X-ray, region causes the ionospheric disturbance. Further, data from the disk and limb define the distribution of flares with height above the surface of the sun. This analysis is important in the prediction of terrestrial effects of solar flares. Dr. J. Warwick has carried out further studies in the physics of the formation of absorption lines, polarization in prominences, and the change in intensity of lines due to the magnetic field of a sunspot.

Mr. Richard B. Dunn and Mr. Frank Q. Orrall have put into operation the 16-inch Baker-Schupmann telescope, previously described. These men aim toward studies of the struc-

ture of the chromosphere and prominences under extremely high magnification and resolving power. The analyses of chromosphere and prominences form the Ph.D. thesis research for Dunn and Orrall, respectively.

Dr. John W. Evans, Director of the Upper Air Research Observatory, reports that a part of the optics of the 16-inch coronagraph has been temporarily mounted for preliminary photographs. These records emphatically confirm the enormous superiority of a large coronagraph under good seeing conditions. With this instrument and the Baker-Schupmann mentioned above, we are now in a position to make the first high-resolution studies of the structure of the chromosphere at times other than during a solar eclipse.

Dr. Walter O. Roberts of the High Altitude Observatory, reports that the principal overall effort in Boulder and Climax has centered around attempts to lay the basis for more accurate solar-terrestrial studies. Under Air Force sponsorship, analysis of the various indices of solar activity has been in progress, with the expectation of producing a handbook that summarizes these indices and evaluates their significance. A second major effort lay in the study of the solar corona, its origin and effects on the terrestrial atmosphere. A third direction of activity consisted of work on solar granulation and on solar spicules, with the hope of finding a possible relation between the two phenomena. Finally, the program of research on the chromosphere, from observations of the 1952 eclipse, continues in full force.

The staff at HAO was strengthened by the one-year visit of Dr. Jean-Claude Pecker and Dr. Charlotte Pecker from the University of Clermont-Ferrand. Dr. R. G. Athay and Dr. E. Billings continue, with Dr. Roberts, to form the nucleus of the staff. Dr. J. H. Rush left in July.

The second consecutive year of the summer session at HAO was again conducted under the direction of Dr. Roberts and Dr. Thomas. For the first time, HAO and HCO jointly sponsored a fellowship for a Harvard graduate student, Mr.

J. B. Zirker, who spent the summer at HAO. It should be noted that three graduate students, Dunn, Orrall, Zirker, are now writing theses on material obtained from the cooperative program between UARO-HCO-HAO. Further, one other student, Satoshi Matsushima, received his Ph.D. for work under the HCO-HAO cooperative program. Matsushima, who accompanied Dr. Thomas to Harvard, received the degree from Utah. The research program of these summer sessions, based upon the 1952 eclipse observations, continues at an expanded rate.

The collaborative theoretical study, initiated by HAO and HCO with J. C. Pecker and C. Pecker at the University of Clermont-Ferrand in France, attempts to delineate the boundary between the solar photosphere and chromosphere.

The remaining studies on the Cambridge solar program were mainly theoretical in nature. During the last year, we have found an ever-increasing need for improved methods for handling the basic physics of gas dynamics, both with and without a magnetic field. The astrophysical applications of gas dynamics overlap with just those problems of current interest in aerodynamics. This circumstance is particularly fortunate, since our theoretical analyses find immediate application in various practical fields of engineering physics. At the same time, this outside interest provides additional data for observational check on theory. We are forced to examine the validity of the fundamental equations, as well as discuss their solution. This example provides a further example of our heavy emphasis on cross-field aspects.

Dr. Max Krook, collaborating with Dr. E. P. Gross of Massachusetts Institute of Technology, has sought to devise a model for the approximate representation of collision processes in gases. Because of our ignorance of collision cross-sections for relatively low-energy processes occurring in atomic collisions, special techniques are necessary to bypass theoretical difficulties. Dr. Krook has further worked with Mr. H. E.

Petschek on the effects of a radiation field on the structure of a shockwave, using methods similar to the above.

Dr. Krook and Dr. David Layzer have used analogous techniques to investigate the stability of shockwaves, with the additional complication caused by the coupling between moving atoms and the radiation field. One of the main objects of the study is an understanding of the mechanism that produces enhanced radio emission from the solar atmosphere. Along the same direction, Dr. Layzer has completed one phase of his study of the stability and structure of flame fronts.

Dr. Layzer has completed his study of the origin of astronomical systems — both stellar and planetary — from the standpoint of a relativistic approach to gravitation clustering.

Dr. Harold Zirin has continued his work on the construction of a model of the solar interior, according to his revised computations of stellar opacity. Working with Professor Philip Morse and members of the physics department of Massachusetts Institute of Technology, he has carried out computations on the wave functions of light atoms. In collaboration with Dr. D. E. Billings of the HAO, he has commenced a study of the physical state of a solar prominence.

Dr. R. N. Thomas has continued his joint research program with Dr. R. G. Athay, Dr. J-C. Pecker, Dr. S. Matsushima, of the HAO and with Mr. J. B. Zirker of HCO on the analysis of the state of the chromosphere at the time of the 1952 eclipse. The preliminary analysis of the hydrogen spectrum has been completed. The analysis of helium, the metals, and chromospheric variability continues. A short investigation on the solar granulation was completed and published during the year.

Mr. Dunn built a permanent chromospheric camera with a narrow-band filter transmitting the red line of hydrogen and the yellow line of helium. Full provision has been made for accurate photometric calibration, including an extra fainter image of the photosphere. Mr. Dunn and Mr. Orrall have already obtained some magnificent motion pictures of the

chromosphere and small prominences, at 4-second intervals between exposures.

Dr. Evans has devoted considerable time to planning for the 13-meter spectrograph, which is scheduled for delivery during December, 1954. The contour densitometer was delivered in August and is currently functioning with a temporary optical system.

Mr. Dunn designed an optical filter system (including a modulating birefringent filter) for a night-sky photometer that registers the atmospheric sky glow in the green and red auroral lines and the yellow (D) lines of sodium, for a special program of the Geophysics Research Directorate of the Air Forces, under Dr. Edward Manring. Tests indicate that this instrument is sensitive enough to detect faint sky glow, even against the background of full moonlight.

Mr. Orrall has studied the theoretical aspect of prominence temperatures and densities, as a prelude to his special observing program, currently underway at UARO. Dr. Evans devised and built a small stereospectrograph for determining the radial velocities of emission-line objects, prominences in particular. The results have been most satisfactory and the device is extremely ingenious. Any area of a prominence moving toward the observer, seems to lie in front of the stationary body, in stereoscopic projection. Similarly, areas moving away seem to lie behind. Mr. Orrall has added a reference of zero velocity, by inserting two points in the field and illuminating them by a hydrogen discharge.

Professor Menzel has continued work in magnetohydrodynamics jointly with Dr. Krook and Dr. Layzer. The investigations have led to interpretation of many dynamic properties of stellar atmospheres in terms of forces produced by electric currents. The theory applies specifically to clouds of ionized gas in the solar atmosphere. Professor Menzel showed that these electrodynamic forces may be important for the production of novae, as well as for the formation of the solar system.

Professor Menzel has studied the opacity coefficient for radio waves traversing an ionized gas. He has carried through theoretical analysis of the E-layer of the ionosphere and, jointly with Mr. Wolbach, has applied it to the available observations of the ionosphere. The variations with the sunspot cycle are evident.

Professor Menzel also devoted considerable time to study of the aurora borealis, to general properties of the auroral zone, and to the morphology of magnetic storms. During March he spent one week at the University of Alaska, College, Alaska, in direct conference with persons working on auroral problems. In addition, he has been active in the coordination of auroral studies for the coming International Geophysical Year.

Professors Whipple and Menzel have collaborated on a study of the atmosphere of Venus, which leads them to conclude that the clouds of that planet consist of water vapor and not of dust, as has hitherto been supposed. They also suggest that surface of the planet may be entirely covered by oceans.

Professor Menzel, Dr. Zirin, and Mr. Wolbach observed the total solar eclipse of June 30, 1954, from a Stratocruiser provided by Northwest Orient Airlines. The flight started in Minneapolis, Minn., and reached an altitude of 20,000 feet. They obtained a few direct photographs of the corona and a low-dispersion record of the flash spectrum, in color.

Professor Menzel prepared, at the request of UNESCO, a detailed Report on the Sources and Uses of Energy in Arid Zones. This report, which contained an extensive bibliography, summarized the general problem of the practical use of solar energy for various purposes, from heating a house or cooking a meal, to the generation of electric power.

In February, 1954, Professor Menzel presented the Rushton Lectures at Birmingham Southern College, Birmingham, Ala. The overall title, "The Universe in Action," comprised these lectures: "The Pattern of Creation," "Other Worlds than Ours," and "The Bounds of Space and Time." In June, 1954

Professor Menzel was awarded the honorary degree of Doctor of Science from the University of Denver, Denver, Colorado.

The following people have worked on the solar project, with major activity in Cambridge, during the past year: Professor Donald H. Menzel, Dr. Richard N. Thomas, Dr. Barbara Bell, Mr. Harold Glazer, Dr. Max Krook, Dr. Salah Hamid terminated July 1, 1954, Dr. David Layzer, Mr. Harry E. Petschek terminated June 15, 1954, Dr. William Sinton, Mr. John G. Wolbach, Dr. Harold Zirin, Mrs. Velma A. Adams, Mrs. Henriette H. Grindley terminated Oct. 15, 1953, Mrs. Sue M. Hazlett terminated March 17, 1954.

The following people have worked on or with the solar project, with special responsibility at Sacramento Peak: Dr. John W. Evans, Mr. Edward H. Bergstrom, Jr. terminated Feb. 28, 1954, Mr. Howard L. DeMastus, Mr. Richard Dunn, Mrs. Alice Dunn, Mr. James P. Foster terminated Dec. 15, 1953, Mr. Frank Q. Orrall, Mr. Harry E. Ramsey, Mr. George K. Schnable, Dr. Constance S. Warwick, Dr. James W. Warwick, Dr. Ching-Sung Yü, Mrs. Gladys M. Day, Mr. Clyde E. Heaston, Mrs. Janet Heaston, Mr. Robert C. Mitchell terminated August 31, 1954.

The Air Force, through their Cambridge Research Center, furnishes additional men for scientific operation of the Upper Air Research Observatory. Dr. Evans, superintendent of UARO, and Mr. Dunn and Mr. Orrall, are officially Air Force personnel, at the present time. The Air Force also provides the basic day-to-day operation, such as utilities, roads, maintenance of housing and vehicles, fire patrol, mess facilities, and, in general takes care of all problems in "logistics," to use the military terminology. This phase of the operation has been capably managed by Captain Lewis Logan, of the U. S. Air Forces.

Within the Department of Astronomy, the graduate curriculum in astrophysics has undergone complete reorganization, with greater emphasis on the subject of stellar atmospheres, with special reference to the sun and stars having

distended atmospheres. Four one-semester courses on general atmospheres have been established, taught by Mrs. Gaposchkin and Dr. Thomas. Three one-semester courses, taught by Professor Menzel, Dr. Thomas, and other members of the solar group, emphasize problems of the sun and solar atmospheres. The course in Astronomical Geophysics further emphasizes the important cross-field aspects. We believe that it is the first course in solar-terrestrial relationships to have been instituted at an astronomical observatory.

The research aspects in stellar atmospheres represent a continuation of our attempts to adopt the methods of contemporary ultraspeed aerodynamics to the solution of problems in astrophysics. One significant problem of current interest is the study of progressive-wave and shock-wave phenomena in the atmospheres of cepheid variable stars. Mr. C. A. Whitney has been awarded an NSF predoctoral fellowship to continue this work with Dr. Thomas. This work has paralleled the solar studies carried out by Dr. Krook, Dr. Layzer and Mr. Petschek. Mr. Whitney presented a summary report at the Symposium on Stellar Atmospheres at Indiana University in September, 1954.

Dr. Dorrit Hoffleit reports that work under the National Science Foundation Grant for studying variable stars in Milky Way Field 193 has proceeded nicely, with the help of one full-time and four part-time, short-term assistants. Positions have been determined for 450 unpublished variables. Magnitudes for 300 have been estimated on 30 or more selected plates. The variables that appeared to be long-period were examined on a sufficient additional number of plates for the determination of approximate periods. Sixty periods have been found. Provisional considerations indicate a mean distance of 6.5 kiloparsecs for the 60 stars. They lie on the outskirts of the galactic nucleus, about 14° from the center.

One nova has been found and studied by Mrs. Dishong who examined over 800 plates.

Although the ONR grant for the investigation of O and

B stars in Carina and Sagittarius has been expended, the project still continues. Dr. Hoffleit obtained the spectral and luminosity classes, apparent magnitudes and colors of over 100 stars. Some 225 separate spectra were classified and more than 25 additional plates recently received from Boyden Station await analysis. The photoelectric photometer records for magnitudes and colors, obtained by Mr. and Mrs. Henry Smith at Boyden Station, were reduced here, partly by Campbell Wade. A paper on this investigation is contemplated for the near future.

Some 50 ADH spectrum plates on selected Carina, Sagittarius and a few other fields have been received from South Africa. More are en route. Work on these plates has been started. Dr. Hoffleit plans to classify all objects suitable for luminosity classification and to study the distributions of all faint stars that will aid in the interpretation of the galactic structure, including the distribution and characteristics of faint emission objects. Some 50 emission objects in Sagittarius have been investigated, many of them new.

Dr. Sergei I. Gaposchkin, has worked on the Andromeda galaxy (Messier 31), on the globular cluster 47 Tucanae in conjunction with the Small Magellanic Cloud, on Omega Centauri, and on a few individual stars.

He has derived the light curves and periods for over two hundred variables found in the spiral galaxy Messier 31, based on his own observations secured during a recent visit to Pasadena, from photographic plates taken with the 200-inch reflector at Palomar. The magnitudes are still not available, but most of the material is ready for publication. A complete record of his observations (some 20,000) has been prepared and will be sent West to fulfill the desire of Mt. Wilson and Palomar astronomers, that observations made with the 200-inch reflector be kept in Pasadena.

A paper on the fascinating problems of the eclipsing variable Epsilon Aurigae has been published. The variable, ZZ Bootis, recently discovered by Dr. S. Gaposchkin, has proved

to allow exceptional precision in the determination of stellar dimensions. Nova Monocerotis 1942, was also studied.

Dr. Gaposchkin has embarked on an extensive program of determining Population diagrams for the globular clusters 47 Tucanae and Omega Centauri, which are the brightest and most extreme examples of these objects. He is also extending his work to include the Small Magellanic Cloud. For his studies, he has successfully used the new Eichner Photometer, and expects to use it for many future programs.

The scale and scope of research in astronomy are expanding rapidly. For the future, we plan to train a larger number of advanced students, and to emphasize cooperative cross-field research projects.

Donald H. Menzel
Director

Appendix

I. Conferences

A. September, 1953. American Physical Society, Albuquerque, New Mexico.

1. "Photographic Meteor Orbits and Their Distribution in Space" — Fred L. Whipple.

B. September, 1953. National Science Foundation Conference on Winds in the Upper Atmosphere, Albuquerque, New Mexico.

1. "High-Altitude Winds by Meteor-Train Photography" — Fred L. Whipple and William Liller.

C. October 4–7, 1953. International Scientific Radio Union, Ottawa, Canada.

1. "Theoretical Interpretation of Solar Phenomena" — Donald H. Menzel.

D. December, 1953. Cosmic Ray Conference, Duke University, Durham, North Carolina. Attended by Max Krook.

E. December 27–30, 1953. American Astronomical Society, Nashville, Tennessee.

1. "Distribution of M- and Carbon-Stars in the Southern Milky Way" — Elske van Panhuys Smith and Henry J. Smith.
2. "On the Borders and Boundaries of the Milky Way" — Harlow Shapley and Ann B. Hearn.
3. "Is the Origin of the Solar System Connected with the Over-all Structure of the Universe?" — David Layzer.
4. "Nova Tucanae 1952" — Henry J. Smith.
5. "Some Characteristics of Solar Flares" — Constance S. Warwick.
6. "A Magneto-Hydrodynamic Theory of the Origin of the Solar System" — Donald H. Menzel.
7. "The Equations of Transfer for Line Formation" — James W. Warwick.
8. "Interpretation of a Photometric Analysis of a Perseid Spectrogram" — Allan F. Cook, II.

9. "The Photographic δ Aquarid Meteor Stream" — Frances W. Wright, Luigi G. Jacchia, and Fred L. Whipple.
10. "The Stebbins-Whitford Effect" — H. Bondi.

F. December 30, 1953. American Association for the Advancement of Science, Boston, Mass.

1. Symposium on Radio Astronomy organized by Bart J. Bok and associates. H. I. Ewen and A. E. Lilley reported on the work at Agassiz Station.
2. Symposium on Meteorites, "On the Origin of Meteorites" — Fred L. Whipple. "Comment on the Meteorite Pitting Phenomenon" — R. N. Thomas.

G. January, 1954. Symposium in Washington, D. C., under the auspices of the National Science Foundation. Bart J. Bok and Harold I. Ewen spoke at this meeting.

H. February 3, 1954. Conference at the U. S. Weather Bureau, Washington, D. C. Fred L. Whipple acting as Chairman of a working group to define a standard atmosphere.

I. April 26–28, 1954. Ninety-First Annual Meeting of the National Academy of Sciences, Washington, D. C.

1. "Solar Activity and Terrestrial Disturbances" — Donald H. Menzel.
2. "Evidence for Winds in the High Atmosphere" — Fred L. Whipple.

J. June 20–23, 1954. American Astronomical Society, Ann Arbor, Michigan.

1. "Solar Corpuscular Emission Responsible for Geomagnetic Disturbances" — J-C. Pecker and W. O. Roberts.
2. "Study of Profiles of Coronal Emission Lines" — D. E. Billings, J-C. Pecker and W. O. Roberts.
3. "Flare Height and SID Occurrence" — Constance S. Warwick.
4. "21 cm. Research at Agassiz Station" — Bart J. Bok and Harold I. Ewen.
5. "21 cm. Analysis of the Taurus Dark Nebulae Complex" — A. Edward Lilley.

6. "Investigations of the 21 cm. Line in the Section of the Galactic Center" — David S. Heeschen.
7. "The Physical Theory of Meteors. VIII. Fragmentation as Cause of the Faint-Meteor Anomaly" — Luigi G. Jacchia.
8. "A Comet Model. III. The Zodiacal Light" — Fred L. Whipple.
9. "The Evidence for Water on Venus" — Donald H. Menzel and Fred L. Whipple.
10. "Theoretical Spin-Orbit Constants for p^2 Configurations" — Harold Zirin.
11. "A Model of the Chromosphere from 1952 Eclipse Data" — R. G. Athay, J-C. Pecker, and R. N. Thomas.
12. "The Polarization of D_3 in Prominences" — James W. Warwick.
13. "Some Emission Stars in the Large Magellanic Cloud" — Henry J. Smith.
14. "Stereoscopic Measurements of Prominence Motions" — John W. Evans.

K. July 1–5, 1954. Rydberg Conference, Lund, Sweden. Cecilia Payne-Gaposchkin was present and contributed a paper on the spectra of rotating stars.

L. July 15–17, 1954. International Astrophysical Symposium on Solid Particles in Astronomical Objects, Liege, Belgium.

1. "The Relative Concentration of Interstellar Hydrogen and Cosmic Dust" — Bart J. Bok.
2. "The Borders of the Southern Milky Way" — Harlow Shapley and Ann B. Hearn.
3. "A Comet Model. III. The Zodiacal Light" — Fred L. Whipple.

M. July 20–22, 1954. Conference on the Physics of the Meteoric Process, Manchester, England. Attended by Richard N. Thomas, Fred L. Whipple, Luigi G. Jacchia, and Allan F. Cook, II.

1. "The Physical Theory of Meteors. VII. On Meteor Ionization and Luminosity" — Fred L. Whipple.
2. "The Physical Theory of Meteors. VIII. Fragmentation as Cause of Faint-Meteor Anomaly" — Luigi G. Jacchia.

3. "The Nature of Meteoric Radiation" — Allan F. Cook, II.
4. "Heat Transfer and the Ablation Process in Meteors" — Richard N. Thomas.

N. August 16–18, 1954. Mixed Commission on the Ionosphere, Brussels, Belgium.

1. "Variations of the E-Layer" — Donald H. Menzel and John Wolbach.
2. "The E and F_1 Layers and Their Associated Problems in Low-Pressure Physics" — Sir Edward Appleton, Professor Massey, Professor Vegard, Dr. D. H. Menzel, and Dr. Nicolet.

O. August 20–September 2, 1954. International Scientific Radio Union, The Hague, Holland. Donald H. Menzel, John Wolbach, and Harold I. Ewen attended this meeting. H. I. Ewen presented the results obtained by the Agassiz Station Radio Astronomy Project. D. H. Menzel and John Wolbach summarized their work on ionospheric research. D. H. Menzel reported on a program of auroral observations and theoretical interpretation, with special reference to the International Geophysical Year.

P. August 30–September 2, 1954. Fourteenth Conference on Science, Philosophy and Religion, Cambridge, Massachusetts. "Symbols and Society."

1. "Galaxies and Their Human Worth" — Harlow Shapley.

Q. September 6–9, 1954. Conference on the Physics of the Ionosphere, Physical Society of Great Britain, Cavendish Laboratory, Cambridge, England. John Wolbach attended to present studies of solar activity and ionospheric effects.

R. September 8–14, 1954. National Bureau of Standards Dedication Scientific Meetings, Boulder Laboratories, Boulder, Colorado.

1. "On the Escape of Ionized Gases from the Sun" — Donald H. Menzel.
2. "The Sun and Radio Communication" — Donald H. Menzel.

S. September 15–29, 1954. International Union of Geodesy and

Geophysics, Rome, Italy. John Wolbach attended, representing Harvard Observatory on general ionospheric and geophysical problems.

T. September 30–October 2, 1954. Symposium on Stellar Atmospheres, University of Indiana, Bloomington, Indiana. R. N. Thomas and C. A. Whitney attended.

1. "Comment on the Solar Chromosphere" — Richard N. Thomas.
2. "Recent Work on Cepheid Atmospheres" — Charles A. Whitney.

U. October 1–4, 1954. Special Committee of the International Geophysical Year plenary session, Rome, Italy. John Wolbach represented Harvard Observatory with special reference to the aurora borealis.

II. Publications for the Year 1953–54

A. The following regular publications have been issued during the year by the Observatory.

Announcement Cards:

Nos. 1225–1275. Report on comets, novae, asteroids, variable stars, etc.

Reprints:

Nos. 374–390.
Series II, Nos. 51–65.

B. The following Scientific Reports were issued during the year on government contracts for research work at the Observatory.

Contract AF19(604)–146

Scientific Report No. 13, November 15, 1953 — "Theory of Linear Flame Propagation" — David Layzer.

S.R. No. 14, January 22, 1954 — "Some Characteristics of Solar Flares" — Constance S. Warwick.

S.R. No. 15, January 27, 1954 — "Is the Origin of the Solar System Connected with the Overall Structure of the Universe?" — David Layzer.

S.R. No. 16, January 29, 1954 — "Comment on the Solar Granulation" — Richard N. Thomas.

S.R. No. 17, July 1, 1954 — "Geomagnetism and the Emission-Line Corona, 1950–53" — Barbara Bell and Harold Glazer.

S.R. No. 18, July 28, 1954 — "Effect of Plate Threshold on Apparent Intensities of Coronal Lines" — Harold Glazer and Barbara Bell.

S.R. No. 19, August 12, 1954 — "Variations of the E-Layer" — Donald H. Menzel and John G. Wolbach.

C. Publications by Observatory Staff members during 1953–54.

ATHAY, R. C. See J. W. Evans and R. N. Thomas.

BELL, B.

"Solar Variation as an Explanation of Climate Change," in *Climatic Change, Evidence, Causes, Effects*, Harvard University Press, 1953.

See also D. H. Menzel.

BHATNAGAR, P. L.

"Internal Constitution of the Sun and Climatic Changes," in *Climatic Change, Evidence, Causes, Effects*, Harvard University Press, 1953.

See also F. L. Whipple and M. Krook.

BILLINGS, D. E.

An Isophotal Contour Densitometer, with F. E. Fowler and D. S. Johnson, J.O.S.A., *43*, 63, 1953.

Formation of the Sun's Corona, Sky and Telescope, *13*, 252, 1954.

Photospheric Magnetic Fields Preceding Other Solar Activity, Astrophysical Journal, *120*, 184, 1954.

See also W. O. Roberts, J-C. Pecker, J. W. Evans, and R. N. Thomas.

BOK, B. J.

Astronomical Problems Connected with the 21c Line, Journal of Geophysical Research, *59*, 192, 1954 (Harvard Reprint No. 383).

Radio Studies of Interstellar Hydrogen, Sky and Telescope, *13*, 408, 1954.

DIMOCK, D. L. *See* R. N. Thomas.

DOLDER, F. P. *See* W. O. Roberts.

EVANS, J. W.

Intensities in the Balmer Lines and Continuum at the 1952 Eclipse, with R. G. Athay, D. E. Billings and W. O. Roberts, (Abstract) Astronomical Journal, *58*, 210, 1953.

Emission in the Hydrogen Balmer Lines and Continuum in the Flash Spectrum of the 1952 Total Solar Eclipse at Khartoum, Sudan, with R. G. Athay, D. E. Billings and W. O. Roberts, Astrophysical Journal, *120*, 94, 1954.

The Active Region on the West Solar Limb During the Eclipse of 25 February 1952, with R. G. Athay, and W. O. Roberts, (Abstract) Astronomical Journal, *59*, 182, 1954.

"The Birefringent Filter," in *The Sun*, University of Chicago Press, 1953.

"The Lyot Coronagraph," in *The Sun*, University of Chicago Press, 1953.

Filter Observations of the Sun, Leaflet of the Astronomical Society of the Pacific, 303, August, 1954.

See also D. H. Menzel.

FOWLER, F. E. *See* D. E. Billings.

GAPOSCHKIN, C. H. P.

Introduction to Astronomy, Prentice-Hall, Inc., 1954.

GAPOSCHKIN, S.

The System of Epsilon Aurigae, Publications of the Astronomical Society of the Pacific, *66*, 112, 1954.

The Eclipsing System ZZ Bootis, Astronomical Journal, *59*, 196, 1954.

Nova Monocerotis 1942, Astronomical Journal, *59*, 199, 1954.

GRENCHIK, R. *See* W. O. Roberts.

HEARN, A. B. *See* H. Shapley.

HOFFLEIT, E. D.

Early History of High-Speed Digital Machines at BRL, Ordnance Computer Newsletter, Vol. *1*, 3, 1954.

The Origin and Age of Meteorites, a report on the AAAS Symposium at Boston, Sky and Telescope, April, 1954.

News Notes, Sky and Telescope (a page a month or about 80 items a year).

Book Review: Harrison Brown, "A Bibliography on Meteorites," Sky and Telescope, March, 1954.

Wachmann's Flare Star, with W. J. Luyten, Astronomical Journal, *59*, 136, 1954.

Magellanic Clouds XI. Survey of the Novae, with Karl Henize and V. Nail, Proceedings of the National Academy of Sciences, *40*, 365, 1954 (H.R. 387).

JACCHIA, L. G.

High-Altitude Ultra-Speed Ballistics of Meteors, Ordnance Research Bulletin, No. 4, April, 1954.

JOHNSON, D. S. *See* D. E. Billings.

KROOK, M.

"Interstellar Matter and the Solar Constant," in *Climatic Change, Evidence, Causes, Effects*, Harvard University Press, 1953.

A Model for Collision Processes in Gases, with P. L. Bhatnagar and E. P. Gross, Physical Review, *94*, 511, 1954 (H.R. Series, II, No. 57).

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Theory of Linear Flame Propagation. I. Existence, Uniqueness, and Stability of the Steady State. II. Structure of the Steady State, Journal of Chemical Physics, February, 1954.

Is the Origin of the Solar System Connected with the Structure of the Universe? Astronomical Journal, *59*, 170, 1954.

LIEBENBERG, D. H. *See* W. O. Roberts.

MATSUSHIMA, S. *See* R. N. Thomas.

MENZEL, D. H.

The Variation in Prominence Distribution over the Sunspot Cycle, with Barbara Bell, Proceedings of the Convegna Volta, Italy (H.R. 380).

The Behavior and Classification of Solar Prominences, with J. Evans, Proceedings of the Convegna Volta, Italy (H.R. 381).

"On the Causes of the Ice Ages," in *Climatic Change, Evidence, Causes, Effects*, Harvard University Press, 1953.

"Solar Activity and the Earth," publication for *Book of Knowledge*, co-authored with Elizabeth Menzel, 1954.

Arid Zone Programme, Report on the Sources and Uses of Energy in Arid Zones, UNESCO publication, 1954.

NAIL, V. MCK.

Magellanic Clouds: IX. The Nebulosities of the Small Cloud, with C. A. Whitney and C. M. Wade, Proceedings of the National Academy of Sciences, *39*, 1178, 1953 (H.R. 377). *See also* H. Shapley and D. Hoffleit.

PECKER, C. *See* W. O. Roberts and J–C. Pecker.

PECKER, J–C.

L'Etude du mouvement spacial dans les protuberances solaires," with D. E. Billings, Comptes Rendus, *238*, 169, 1954.

A Comment on the Formation of Emission Lines, with C. Pecker, (Abstract) Astronomical Journal, *59*, 188, 1954.

ROBERTS, W. O.

Isophotal Photometry of a Solar Flare, with D. E. Billings, Astrophysical Journal, *118*, 429, 1953.

Recent Studies of Chromospheric Spicules, with J. H. Rush, (Abstract) Astronomical Journal, *58*, 226, 1953.

Origin of White Light Coronal Streamers, with R. Grenchik, and D. E. Billings, (Abstract) Astronomical Journal, *58*, 225, 1953.

Evolution of Coronal Regions, with D. E. Billings and D. H. Liebenberg, (Abstract) Astronomical Journal, *58*, 211, 1953.

Solar Flares and the Yellow Coronal Line, with F. P. Dolder and D. E. Billings, Astrophysical Journal, *119*, 120, 1954.

Solar Spicules and their Role in Solar Phenomena, with J. H. Rush, Trans. of I.R.E., CS-2, 24, 1954.

Recent Studies of Chromospheric Spicules, with J. H. Rush, Australian Journal of Physics, 7, 230, 1954.

Etude de l'elargissement de la raie rouge coronale dans les centres actifs, with D. E. Billings and C. Pecker, Comptes Rendus, *238*, 1194, 1954.

Determination de l'atome responsable de la raie jaune coronale λ 5694.4, with D. E. Billings and C. Pecker, Comptes Rendus, *238*, 1101, 1954.

Active Region Prominences and the Yellow Coronal Emis-

sion Line, with D. E. Billings and F. P. Dolder, Astrophysical Journal *120*, 112, 1954.
See also J. W. Evans.

RUSH, J. H.

Further Evidence of 15,000 km. Cellular Structure in the Solar Photosphere, with F. E. Stuart, (Abstract) Astronomical Journal, *58*, 231, 1953.

Evidence of the 23-year Cycle in Recurrent Magnetic Storms, with D. E. Trotter, (Abstract) Astronomical Journal, *59*, 191, 1954.
See also W. O. Roberts.

SHAPLEY, H.

"On Climate and Life," in *Climatic Change, Evidence, Causes, Effects*, Harlow Shapley editor, Harvard University Press, 1953.

Note on the Extragalactic Distance Scale, Astronomical Journal, *58*, 227, 1953.

Report on Programmes of Galactic Measurement, The Irish Astronomical Journal, *2*, 181, 1953 (H.R. 375).

The Expanding Universe, Gentry, No. 8, 1953.

Magellanic Clouds: VIII. On the Population Characteristics of the Two Clouds, Proceedings of the National Academy of Sciences, *39*, 1161, 1953 (H.R. 376).

Life on Other Planets, The Atlantic Monthly, *192*, No. 5, 1953.

Edwin P. Hubble, Year Book of the American Philosophical Society, 1953.

A Test for High Altitude Absorption as a Factor in the Distribution of Galaxies, Publications of the Astronomical Society of the Pacific, *65*, 386, 1953.

The Borders of the Milky Way, with A. B. Hearn, Astronomical Journal, *59*, 169, 1954.

Note on the Light Variations of Proxima Centauri, Astronomical Journal, *59*, 118, 1954 (H.R. Series II-55).

New Variable Stars in Centaurus, with L. B. Allen and N. Greenstein, Astronomical Journal, *59*, 270, 1954.

Magellanic Clouds: X. An Evaluation of Zero Point Correction, with V. McK. Nail, Proceedings of the National Academy of Sciences, *40*, 1, 1954 (H.R. 382).

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The Physical Theory of Meteors. V. The Masses of Meteor-Flare Fragments, Astrophysical Journal, *119*, 438, 1954.

Observation of a Nova in the Small Cloud, Proceedings of the National Academy of Sciences, *40*, 365–373, 1954 (H.R. 388).

STUART, F. E. *See* J. H. Rush.

THOMAS, R. N.

Analysis of the Balmer Continuum from the 1952 Eclipse, with D. L. Dimock, D. E. Billings, and R. G. Athay, (Abstract) Astronomical Journal, *58*, 213, 1953.

Departures from Thermodynamic Equilibrium and Self-Absorption in the Balmer Line Spectrum from the 1952 Eclipse, with S. Matsushima, R. G. Athay and C. A. Whitney, (Abstract) Astronomical Journal, *58*, 238, 1953.

Physical Theory of Meteors. IV. Inquiry into the Radiation Problem — A Laboratory Model, with W. C. White, Astrophysical Journal, *118*, 555, 1953.

Commentaire sur la granulation solaire, Bulletin de l'Academie Royale de Belgique, *40*, 621, 1954.

TROTTER, D. E. *See* J. H. Rush.

WHIPPLE, F. L.

On the Icy Conglomerate Model for Comets, Mem. Roy. Soc. Sci. of Liege, *23*, No. XIII, 1953.

Winds in the Upper Atmosphere by Meteor-Train Photography, Journal of Meteorology, *10*, 390–392, 1953.

Conquest of the Moon, with W. von Braun and W. Ley, Viking Press, New York, 1953.

On The Secular Accelerations of Phobos and Jupiter V, with Frank J. Kerr, Astronomical Journal, *59*, No. 3, 124–127, 1954.

Accretion of Matter by a Satellite, with P. L. Bhatnagar, Astronomical Journal, *59*, No. 3, 121–124, 1954.

High-Altitude Winds by Meteor-Train Photography, with William Liller, *Rocket Exploration of the Upper Atmosphere*, edited by R. L. Boyd and M. J. Seaton, published by the Pergamon Press, Ltd., London, 112–130, 1954.

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Photographic Meteor Orbits and their Distribution in Space, Astronomical Journal, *59*, No. 6, 201–217, 1954.

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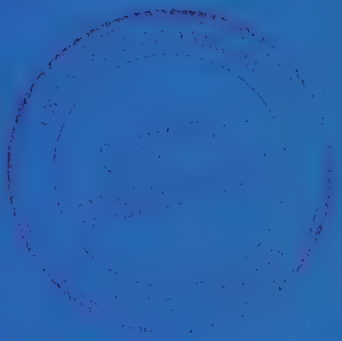
Is There Life on Mars?, Collier's, April 30, 1954.

HARVARD
ASTRONOMICAL OBSERVATORY

ANNUAL REPORT



1955

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Harvard College Observatory

To the Dean of the Faculty of Arts and Sciences:

Sir, — The Harvard College Observatory Council, consisting of Professor Bart J. Bok, Dr. Cecilia Payne-Gaposchkin, Professor Fred L. Whipple, Dr. Richard N. Thomas, Dr. Gerhard Miczaika, and myself, Donald H. Menzel, take pleasure in submitting this annual report. It is a satisfaction to record that many of the plans outlined in the 1953 and 1954 reports have been carried out, and others are nearing completion. We are confident that the Observatory will continue to grow and develop, and that the year just beginning will prove a highly significant one.

In the spring of 1955, The Smithsonian Institution and Harvard University agreed to associate their activities in astrophysical research, in order to strengthen and expand the programs of both institutions. On July 1, Dr. Fred L. Whipple became Director of the Smithsonian Astrophysical Observatory, which has moved its headquarters to the campus of the Harvard College Observatory in Cambridge.

As outlined in my reports of the past two years, our major objectives have been to modernize the equipment available for student training at Agassiz Station, to strengthen our scientific staff at the junior level, to enlarge the curriculum for graduate students in astronomy and cross-field sciences, and to initiate a satisfactory plan for operation of the Boyden Station in South Africa. These objectives are now close to realization. Renovation of the physical plant in Cambridge nears completion. An extensive program in radio-astronomy is well under way. Our affiliation with the Smithsonian Astrophysical Observatory is making excellent progress, but the conse-

quent problems of reorganization and of business administration may continue for some time.

At present the possibilities for growth and service in Astronomy seem to be limited only by the inadequacy of funds. We are acutely conscious of the fact that the Observatory now depends so heavily upon government contracts and grants that we can make only short-term appointments, rather than the long-term ones desirable for stability and most efficient operation. We of the Council are unanimous in our conviction that the raising of unrestricted funds for endowment is imperative, if we are to develop our research and teaching programs to their full potential.

We continue our custom of offering a series of "Open Nights" each fall, spring, and summer. We encourage those interested, particularly the children, to visit the Observatory on the scheduled dates, when we provide illustrated lectures, guided tours, and an opportunity to look through the telescopes. Miss Frances W. Wright took charge of "Open Nights" during the past year, during which more than 2000 visitors applied for tickets, and she will continue to organize these evenings for the coming year. Dr. Dorrit Hoffleit arranged the summer series. Lectures were given by Dr. Gerald Hawkins, Professor Donald H. Menzel, Dr. Guido Münch, Dr. William Pinson, Professor Harlow Shapley, Dr. Harold Weaver, and Dr. Dorrit Hoffleit. The new room of astronomical exhibits, when completed, should prove an added attraction for visitors.

On July 1, 1955, six observatories began the operation of the Boyden Station in cooperation, for a two-year period. The observatories participating in this plan are Dunsink Observatory, County Dublin, Eire; Stockholm Observatory, Saltsjobaden, Sweden; Royal Observatory, Uccle, Belgium; Hamburger Sternwarte, Hamburg-Bergedorf, Germany; Astronomical Observatory, Armagh, Ireland; and Harvard College Observatory, Cambridge, Massachusetts. Professor Donald H. Menzel is Chairman of the Administrative Coun-

cil, which met in Dublin in September, 1955, and Dr. P. Bourgeois, of Belgium, is acting as Secretary-Treasurer. The Council plans its next meeting for early summer, 1956, when the main item of discussion will be the problem of providing a long-range plan and permanent management of the Station.

On June 16, 1955, the total number of bound volumes and papers in Phillips Library, Cambridge, was 9,273. During the past year, we acquired a small number of new books, and are making a particular effort to build up our library facilities in the fields of solar research, radio astronomy, and theoretical astrophysics. Funds for the purchase of new books are, however, very limited.

During the year covered by this report, we have accomplished many additions and improvements in the physical plant in Cambridge.

1. Landscaping and planting around new Building A and in the area formerly occupied by the Director's residence.

2. A new parking lot on the site of the former residence.

3. A stone terrace and steps at South Entry, leading to the new parking lot.

4. Resurfacing of the driveway.

5. Demolition of old Building B.

6. Aluminum awnings installed on south side of Building A, at both levels.

7. New cedar picket fence on the north and west boundaries of the property.

8. New chain-link fence, in conjunction with the University, on Concord Avenue, Bond Street, and parts of Garden Street.

9. Modernization of the 15″ telescope and decoration of the dome completed.

10. New Baird microdensitometer installed in the laboratory.

11. The following rooms redecorated:

Building D: Library
Cloak Room
Stairwell
Passageway between C and D buildings, basement floor.

Building C: Ladies' Room, basement floor
C-31, a double office.

Building A: A-25, double office on way to 15″ telescope
15″ telescope room.

12. Asphalt tile laid in cloakroom, 15″ telescope room, A-25.

13. Fluorescent ceiling lights installed in rooms A-25, C-36, D-312, D-313, D-314.

14. New Chevrolet truck purchased for use in maintenance and caretaking, and transportation of equipment and personnel to Agassiz.

15. Architects' plans have been approved for renovating and converting the rotunda into an exhibition room. The basic work of carpentry, plastering, installation of heating and wiring, floor covering and painting, is now under way. Several exhibits and some art work have been started, including the replica of the moon being executed by Mr. Charles Bittinger, the radio telescope model by D. S. Kennedy Co., and a solar mural by Dr. Sergei Gaposchkin.

A grant from the Tozier Fund, plus private donations, makes this work possible.

16. Architects' plans have been approved for converting the old "prime vertical" room into a chart room and a display space for the sundial collection. This room will house star-charts, including Carte du Ciel and the newly issued Mt. Wilson-Palomar Sky Charts, and will provide work space for those studying the charts.

17. The passageway between C and D buildings has been waterproofed and wall covering installed.

18. Both the 9″ and the 7½″ telescopes at the Garden Street plant have been repaired.

19. The yard lights on Building A have been put on a timeclock.

20. Room C-25 has been converted into a drafting and computing room, with equipment available for use by staff and students.

Several necessary improvements remain to be made, whenever funds become available. Among our more urgent needs are: a new machine shop with modern tools; paving of two parking lots; dry wells or sewer drains for proper drainage of the grounds; further landscaping and reseeding of grounds; light-proof shades for the library-auditorium; redecoration and renovation of the basement of Building C, to provide offices and storage facilities.

Our greatest need at present, however, is an addition to our physical plant. The increase of the scientific staff at the Observatory, occasioned by natural growth as well as by the new association with the Smithsonian Astrophysical Observatory, has severely taxed the capacity of the physical plant in Cambridge. We urgently need another major office building.

At the George R. Agassiz Station in Harvard, Massachusetts, the rehabilitation of buildings and equipment progresses well under the supervision of Dr. Gerhard Miczaika. Engineering work on the basic instruments initiated last year, has been almost completed, but detailed work on the auxiliary equipment, such as the Cassegrain spectrograph for the 61″ reflector, is still in the preliminary stage. Mr. W. W. Baustian, chief engineer in charge of the construction of the 120″ reflector at Lick Observatory, and Mr. Joseph Nunn, engineer in Los Angeles, visited the station to discuss construction problems with Dr. Miczaika and to gather data for detailing of parts.

Reconstruction of the 24″ reflector nears completion. An electronic drive, including mechanical parts, has been built

in the Observatory shop. Three motions have been provided for both coordinates, in addition to the drive motion. The operator controls the telescope from a panel, where he can read the position of the telescope, as indicated by selsyn repeaters. Dr. J. G. Baker designed the new Cassegrain optics, made by Mr. James Gagan. Metal Fabricators Corp. of Waltham has constructed and installed a new dome to replace the old sliding roof. Building and telescope had to be completely re-wired. We expect delivery of the new Cassegrain photometer and its amplifier and power supply toward the end of the year.

An addition to the east side of the 61″ building houses the aluminizing equipment and facilities for handling heavy mirrors, as well as a mechanical shop, equipped with new tools. The new aluminizing equipment, made by National Research Corporation, includes a vacuum chamber 72 inches in diameter, a 16-inch diffusion pump, a mechanical holding pump and the necessary electrical control elements.

The larger components for the 61″ now under construction include the mirror cell, the right ascension and declination drive, and the electronic control units. The mirror cell will contain 18 support units for the back of the mirror, 12 for the edge, and 4 for the center hole. Sylphon bellows provide for perfect compensation of the gravitational forces that tend to distort the mirror.

The new drives will completely replace the existing ones. A second large gear, comparable in size to the drive gear, will be provided for the fast motion of the telescope in right ascension. A variable-frequency electric oscillator furnishes power for the synchronous drive. The instrument will possess three different setting rates in right ascension and declination. The telescope will be operable from a main control desk as well as from a substation at the observer's location.

Cell and drives are on order. The electronic components, including the control desk, are under construction in the Ob-

servatory shop. Dr. Miczaika and Mr. John Campbell have laid out the circuits.

Transportation of the mirror from the tube to the vacuum chamber requires an elaborate carriage; the design is completed, and the order will be placed soon.

Re-wiring of light, power, and control elements of the 61″ building has been largely completed, including the installation of heavier feed cables, to meet increased power requirements.

Much work has been done on buildings and grounds. All brick buildings were waterproofed during the summer, all roads repaired and surfaced, and a new road gives access to the site cleared for the 60-foot radio telescope now under construction. An additional number of buildings have been wired for slaves of the IBM master clock installed a year ago.

Mr. Lionel Caron has made a number of accessory parts at the old shop in Cambridge. We enjoyed the cooperation of the Gordon McKay Laboratory, where we were allowed to use precision machinery.

The new electronic laboratory, mentioned in the last report, modest as it still is with its limited facilities, has produced electronic units for drive and control purposes, in addition to equipment for Dr. Sinton's solar eclipse expedition to Ceylon in June.

Most of the research projects mentioned in my previous reports have continued during the past year, and still others have been initiated. Close coordination of the work of staff members at Harvard and at other Observatories has resulted in many collaborative research papers, as you will note in the Appendix listing of publications.

As I mentioned earlier, the Smithsonian Astrophysical Observatory has moved its headquarters to Cambridge, under the Directorship of Professor Fred L. Whipple, who will continue as Professor of Astronomy at Harvard, and thus remains a member of the Harvard College Observatory Council. The two institutions expect to make additional joint appointments in the future.

Late in July, Dr. John S. Rinehart was appointed Assistant Director of the Astrophysical Observatory, and Dr. James E. Zimmerman is the third member of the scientific staff assigned to Harvard.

Measurement of the "solar constant," i.e., the output of energy by the sun, has been a major effort of the Astrophysical Observatory of the Smithsonian Institution. The Observatory has been especially interested in variations in the "constant," and in the possible effects of such variations on radio communication, weather forecasting, and other geophysical phenomena. The Smithsonian Observatories maintained in Montezuma, Chile, and at Table Mountain, California, have both contributed measurements of the constant.

With Harvard collaboration, the Smithsonian contemplates a greatly expanded astrophysical research program, to include both theoretical and laboratory studies of other forms of energy impinging on the earth's atmosphere, especially meteoric bombardment and corpuscular radiation from the sun. These studies are closely related to Harvard's interest in auroral and air glow phenomena.

Of special significance to the Harvard College Observatory and to the Department of Astronomy is the intention of the Smithsonian Institution that their scientific staff in Cambridge "shall be encouraged . . . to engage in limited amounts of teaching. . ."

Under Professor Whipple's direction, the Meteor Projects continue to be one of the important areas of basic research at the Harvard College Observatory. The observation program at the two stations in New Mexico is supported by the U. S. Air Force under contract with the Air Force Cambridge Research Center. Contracts with the U. S. Army Office of Ordnance Research, the Office of Naval Research, and, more recently, with Project Lincoln under an Air Force contract, support the work of reduction and analysis, carried out in Cambridge.

After a long delay, the low-dispersion objective grating of

the replica transmission type, ordered for use with the Super-Schmidt meteor cameras in New Mexico, arrived in September, 1955. Mr. Richard E. McCrosky immediately began tests of the grating.

The New Mexico stations are under the supervision of Mr. Gunther Schwartz. More than 4000 meteors have now been doubly photographed; several dozen persistent meteor trains are now in photographic register, while four have been multiply-photographed simultaneously from the two stations. Dr. Allan F. Cook has supervised the reduction and analysis of the meteor trains. Mr. Robert F. Hughes, with the assistance of Mr. Richard B. Southworth and Mr. John J. Murphy, has measured five of these trains for wind profiles in the high atmosphere, and some forty-eight for statistics on the heights of persistent train phenomena.

Professor Whipple and Dr. Cook have discovered a new method of measuring the mass of an individual meteorite through the transfer of momentum to the surrounding air mass, which produces a forward motion of the persistent meteor train. The new results reconcile some of the discrepancies in the literature concerning the relationships among the Zodiacal Light, comets, and meteoric particles.

Dr. Richard N. Thomas continues his attempts to relate laboratory studies of artificial meteors to meteor observations and hence to contribute toward a physical theory of meteors. He is investigating the pitting phenomenon on a meteor in terms of conditions at the meteor surface, and the problem of ionization caused by artificial meteors.

Dr. Luigi G. Jacchia has continued his research on the deceleration of meteors in the earth's atmosphere. The available data indicate the possible existence of a lower limit for the size of meteor fragments.

A survey of shower meteors has revealed striking differences in the fragmentation of meteors from different showers, indicating a correlation between fragmentability, meteor age and size of the parent comet, in agreement with Whipple's

comet theory. In particular, two such meteors photographed in 1953 have confirmed the exceptional fragility of Giacobinid meteors. Dr. Jacchia's research is based on the results of the accurate meteor reduction program, which he continues to supervise. Much of the computational work involved is now mechanized, and is carried out by Mr. John J. Murphy at the Watson Scientific Laboratories in New York on a card-programmed calculator.

It is a pleasure to acknowledge the generous support given the Meteor Project by International Business Machines, Inc.

Mr. Richard E. McCrosky has developed and put into operation an extremely rapid method for the approximate reduction of photographic meteor trails. He has already measured more than a thousand trails for heights and velocities by his new technique. The statistical analysis of these measures is now underway. He has demonstrated that many of the faint photographic meteors suffer complete fragmentation at the time that the phenomenon is first photographed.

Miss Frances W. Wright has analyzed the radiant motions and scatter for the photographic Delta-Aquarid and Alpha-Capricornid meteors and has nearly completed a similar analysis for the Iota-Aquarid stream. Miss Wright also continues to act as Executive Secretary in the Department of Astronomy.

The meteor projects were fortunate in the fall of 1954 to acquire the assistance of Dr. Gerald S. Hawkins, who transferred from the Radio-Meteor projects at the Jodrell Bank Experimental Station of the University of Manchester, England. His first several months of activity centered about the reduction of shorter meteor trails by a less exhaustive method than that used by Dr. Jacchia for the longer and better-observed photographic meteor trails. The so-called "short-trail method" is now underway for more than a hundred meteors; the calculations are being carried out primarily by the card-programming calculator of International Business Machines.

During the past year, Harvard College Observatory initi-

ated a program of basic research on radio-meteors, supported by Project Lincoln. A preliminary engineering study, to determine the possibilities of such research, indicated that an extensive program of radio-meteor observation has great potentialities for increasing our knowledge of the orbits and physical processes involved in the faint meteors detectable by such equipment. While we await a final decision on our proposal, we have signed a preliminary, less comprehensive research contract with Project Lincoln. Dr. Hawkins will direct the work, and will investigate statistically the orbital characteristics of the radio and photographic meteors so far observed. Dr. Curtis L. Hemenway, on sabbatical leave from the Department of Physics at Union College, will assist.

During the past year Professor Whipple has served on various committees, in various capacities: chairman of the Panel for Astronomy, advisory to the National Science Foundation; chairman of the Panel on Rocketry for the International Geophysical Year under the auspices of the National Research Council; member of the National Committee for the establishment of a Standard Atmosphere; chairman of a committee investigating the detailed problems of specifying a Standard Atmosphere for international use; chairman of a special committee for the National Science Foundation to investigate "New Horizons" in Astronomy. During the year Professor Whipple completed his term of office as Associate Editor of the Astrophysical Journal, and has now assumed the duties of Associate Editor for the Astronomical Journal.

A second full year of operation of the 24-foot radio telescope at the George R. Agassiz Station has resulted in continued progress. Professor Bart J. Bok and Dr. Harold I. Ewen direct the project, assisted by Dr. David S. Heeschen, who returned to Harvard after a year of teaching at Wesleyan University, and by Mr. John A. Campbell, electronic engineer.

Eight graduate students took part in the observational program in radio astronomy this past summer. A doctoral thesis

by Dr. Heeschen, "An Investigation of the 21-cm Line of Neutral Interstellar Hydrogen in the Section of the Galactic Center," has been accepted by the Graduate School. Three other theses are in preparation, and numerous papers have been published on the research carried out by students and staff. During the past year Mr. Robert S. Lawrence from the National Bureau of Standards in Boulder, Colorado, participated in the work of the Agassiz Station and co-authored two published papers.

Professor Bok, as retiring Vice-President of Section D, American Association for the Advancement of Science, gave an address on "The New Science of Radio Astronomy" at the joint meeting of the Astronomical Society of the Pacific and the American Association for the Advancement of Science, December 27–30, 1954, at Berkeley, California. At the same meetings, he presented joint papers with Campbell M. Wade, Robert S. Lawrence, T. K. Menon, and Thomas A. Matthews.

Professor Bok and Professor L. D. Leet are jointly teaching a course sponsored by the General Education Department, entitled "Problems of the Earth and the Universe." The Astronomy Department provides three teaching fellows to assist.

We are fortunate in having with us for the coming year Mr. George Field, a Junior Fellow interested in radio astronomy. During the past year many radio astronomers visited the Agassiz Station, including scientists from Australia, France, Great Britain, and Holland.

Radio astronomy continues to emphasize 21-cm research, which provides necessary information, not available optically, on the behavior of neutral hydrogen in interstellar space. By correlating radio and optical studies, we hope to discover new relationships between interstellar gas and dust.

We expect to have a 60-foot radio telescope in operation by April 1956. Electronic equipment, built by the Ewen-Knight Corporation, will receive radio waves from the equatorially mounted paraboloid antenna, constructed by the D. S. Ken-

nedy Co. This large antenna intercepts radiation from much smaller areas of the sky than does our existing 24-foot "dish."

Research in radio astronomy at the Agassiz Station depends in large measure upon year-to-year gifts and grants. Major support from the National Science Foundation, augmented by anonymous gifts by a friend, make possible the construction of the new electronic laboratory and the 60-foot reflector. Radio astronomy, like other Observatory projects supported on an annual basis, lacks adequate permanent financial support for a graduate training program.

We hope to cooperate with Associated Universities, Inc., in the development of facilities for large radio telescopes. Professor Bok is an active member of the Steering Committee for the study. Additional finances are necessary if Harvard Observatory is to participate in the National Radio Observatory.

Professor Harlow Shapley and his assistants continue to concentrate their research activities on problems relating to the distribution of galaxies, the analysis of the Magellanic Clouds, and on special studies of variable stars. They have measured the inclination of the Magellanic Clouds. A final report on variable stars in the Clouds brings the number of identified variables up to 3696. Studies of colors of Magellanic stars, variable and non-variable, have revealed some extraordinarily red objects. Since the Large Cloud may be a region where stars are currently being born, these stars should be watched in the future for possible evidence of rapid evolution.

Professor Shapley has reviewed, for *The American Scientist*, problems of the Magellanic Clouds, including fifty years of work by many Harvard observers. A census of external galaxies over one fifth of the whole sky has delineated the dust clouds of the southern Milky Way. A monograph on the Inner Metagalaxy, approaching completion, will describe the distribution and properties of several hundred thousand galaxies, and will summarize the hundred papers published by

Dr. Shapley and his collaborators, during the past thirty years.

Investigation of variable stars and galaxies in the anti-center section of the Milky Way continues, to determine the extent of the Milky Way and of its corona of outlying stars, in the region of Taurus and adjacent constellations. Mr. Henry A. Sawyer has made additional photographs at the Agassiz Station for this program. Mrs. Virginia Nail, Miss Jacqueline Sweeney, and Mr. Pedro Kokaras have continued as assistants in these studies.

In the realm of stellar astronomy, the Observatory sponsors numerous individual research programs.

Dr. Thomas and Dr. Cecilia Payne-Gaposchkin together are conducting theoretical studies of the pulsating variable stars, with reference to the gas-dynamical aspects. They are offering a two-semester course intended to provide the background for physical interpretation of variable stars.

Miss Margaret Olmsted has continued her photometric studies of the southern Milky Way. Photographic and photored standard sequences of magnitudes in three of the Harvard Standard Regions are now being transferred to variable star fields of the southern Milky Way, for a study of magnitude variations and colors of remote Cepheid variables. Commission 5 of the International Astronomical Union officially recognized Miss Olmsted's assistance in the preparation of the Astronomical News Letters, edited by Dr. V. Kourganoff of the Observatory in Lille, France.

Dr. Sergei Gaposchkin has pursued his study of variable stars, novae, photometric double stars, and the globular cluster 47 Tucanae. Dr. Gaposchkin has discovered an important double-lined eclipsing variable (HD 77464).

Dr. Dorrit Hoffleit and assistants, working under a grant from the National Science Foundation, have obtained more than 30 estimates of the magnitudes of 450 unpublished variable stars in Milky Way Field 193. Miss Hoffleit has completed one study of O and B type stars in Carina and Sagit-

tarius, and has also investigated photometric effects at the earth's tropopause, from photographs taken from high-altitude balloons.

Dr. Miczaika, together with Mr. Fred Franklin, completed a spectrophotometric investigation of two metallic-line stars on Coudé spectrograms lent by Mount Wilson Observatory.

Our solar program has developed in three main phases: (1) the building of observatories equipped with small coronagraphs which take solar records on a patrol basis; (2) maintenance of observing programs, use of the data so obtained, and design and construction of precision, large-scale solar instrumentation; (3) use of this precision equipment for detailed study of solar features. This year we have entered the third and most exciting phase of the program.

Dr. John W. Evans, Director of the Upper Air Research Observatory on Sacramento Peak, has been largely responsible for the advances in instrumentation. Dr. Richard N. Thomas continues as scientific coordinator of the Harvard solar program.

The scientific staff at Sacramento Peak has been enlarged and strengthened to take advantage of the additional equipment. Henry J. Smith, who has been appointed Astronomer-in-Charge of the Harvard program, has worked in astronomical spectroscopy. He previously served as Acting Superintendent of the Boyden Station in South Africa. Mrs. Elizabeth Evans will assist him in the administrative and clerical operation of Sacramento Peak, and will act as liaison between the Harvard and Air Force groups stationed there.

Mrs. Elske Smith has recently concluded an investigation of polarized light from the southern Milky Way, which contributes to our knowledge of polarization phenomena and the spiral structure of our galaxy.

Richard Dunn has operated the chromospheric camera with the Schupmann telescope described in last year's report. With this equipment Frank Orrall secured numerous high resolution photographs and motion pictures of prominences.

During the year Dunn rebuilt the chromospheric camera, to obtain greater convenience in operation and more certain photometric standards. By abandoning all but the Schupmann objective, he was able to reduce the number of optical surfaces from 35 to 14, which greatly increases the speed of the system. During the summer of 1955, Mr. Dunn obtained a unique daily chromospheric survey and numerous spicule moving pictures. These observations combine high resolution and large scale, and will provide much-needed empirical data on dynamic phenomena in the chromospheric levels of the sun's atmosphere. Sarah Lippincott has carried out an analysis of sizes, distribution, and lifetimes of spicules from these films. Dr. William Sinton recently went to New Mexico to participate in the research and instrumental development. Dr. Harold Zirin also spent considerable time there.

The prominence camera yields significantly more valuable observations with the new coronagraph objective figured by Mr. Chester Cook. A new Lyot-type birefringent filter, built by Richard Dunn, permits observations in Hα, Hβ, D_3 and the red, yellow and green coronal lines.

A new narrow-band filter, also by Dunn, greatly increases the sensitivity and resolution of the camera, used to record sudden brightenings of the solar surface. This flare patrol has detected large numbers of subflares, which formerly were below the threshold of visibility. By tuning the filter to the wings of Hα, the observers have made cinematographic records of the little-understood coarse structure of the solar disk.

The small coronal spectrograph, which for six years has obtained daily observations of red and green coronal line intensities, has also been converted into a more versatile research instrument. Changes include an achromatic secondary optical system, remote control of objective focusing, provision for grating adjustment, and an entrance slit of new design. A new five color tube sensitometer is now available for photometric calibration.

Spectrographic accessories to the 16-inch coronagraph are

now being installed. Dr. Sinton has recently added prisms to form a double-pass spectrograph with the high resolving power of 700,000.

Solar Associates, formed in 1954 to sponsor cooperative research through a personnel exchange program, met twice in 1955, in Cambridge January 19–22 and at Sacramento Peak July 21–22. Professor Whipple, as Director of the Smithsonian Astrophysical Observatory, became a member at the July meeting.

We now have a "Harvard House" on Sacramento Peak for occupancy by transient and exchange members of the Harvard Solar Department. Also, we expect to rotate personnel from Sacramento Peak to Harvard for periods of three to six months.

Three graduate students are currently using solar data as thesis material. Frank Orrall obtained observations of prominences, Richard Dunn is studying spicules, and Jack Zirker has completed the tracing and measurements of all data on the metallic spectrum of the chromosphere. Mr. Orrall, who worked on H-alpha filter observations using the 15-inch modified-Schupmann telescope at Sacramento Peak, will join the group permanently as soon as he has received his Ph.D. degree.

During the year, Professor Menzel, Dr. James Warwick, and Mr. Robert Lawrence reported on requirements for a program to investigate the radio frequency emission from active areas on the sun, and worked out the specifications for the appropriate instrumentation. Under an Air Force contract, we have ordered a dynamic spectrum analyzer from the Airborne Instruments Laboratory, Inc. and a 28-foot paraboloid antenna from the D. S. Kennedy Co. The spectrum analyzer will operate over the frequency band 100–600 megacycles per second to measure radio emissions from the corona and upper chromosphere.

The Harvard program will aim at detailed correlation of the radio measurements with visual data from the new solar

instruments at Sacramento Peak. The radio equipment will be installed as near as possible to Sacramento Peak, consistent with the level of radio interference. Dr. Alan Maxwell, formerly of the Jodrell Bank Experimental Station, Manchester, England, is Astronomer-in-Charge of the solar radio work. Mr. Samuel J. Goldstein from the Department of Electrical Engineering, Stanford University, is his assistant.

In Cambridge, Professor Menzel, Drs. Thomas, Krook, Layzer, Bell, Zirin, Messrs. Wolbach and Glazer carried out an extensive series of research projects. The theoretical group at Cambridge, under Dr. Thomas' leadership, has intensified its activity in designing the programs and analyses of observations that involve the new Sacramento Peak equipment. In particular, they have expanded their program for investigating conditions in the solar atmosphere and in the prominences.

Professor Menzel has extended his studies of solar-terrestrial relationships, and used the results as the basis of a new course termed "Astronomical Geophysics." Research activities included the development of theories of magnetic storms, the aurora borealis, and ionospheric disturbances. Dr. James Warwick and Mr. Robert Lawrence collaborated in these studies. In March, Professor Menzel made a field trip to the University of Alaska, for first-hand study of auroral and magnetic phenomena. The ionospheric studies, undertaken with Mr. John Wolbach and Mr. Harold Glazer, include phenomena of both the E and F_2 ionospheric layers. The new course has as one objective the training of scientists for highly specialized studies of the International Geophysical Year, 1957–58.

Two graduate students, Mr. Campbell Wade and Miss Mary Jane Stewart, were appointed to the Central Radio Propagation Laboratory of the National Bureau of Standards, in Boulder, for the summer of 1955. There they received further training in geophysics, and worked on practical problems.

Dr. Thomas has continued his analysis of the structure of the lower chromosphere, as inferred from the 1952 eclipse

observations made by High Altitude Observatory. Dr. Thomas and Dr. R. G. Athay of High Altitude Observatory, who is in residence at Harvard during 1955–56, are preparing a monograph on the solar chromosphere, summarizing their attempts to construct a physical model of the outer solar atmosphere. They have made major progress, presenting a model which reconciles a number of divergent observations and provides a theoretical basis for the observed behavior. These results were presented at the Manchester Symposium in Radio Astronomy in August 1955.

Dr. Barbara Bell and Mr. Glazer have prepared an analysis of the relation between solar and geomagnetic indices. Mr. Glazer has used the IBM card-programmed calculator to speed up the mathematical computations.

Dr. Layzer has studied the spectra of highly ionized atoms in the carbon sequence, by an original theoretical method. He established that the so-called yellow coronal line comes from fourteen-times ionized calcium. His work shows that the temperature of localized regions of the solar corona must be higher than previously estimated.

Dr. Harold Zirin and Dr. David Layzer have searched for additional coronal lines. Dr. Zirin, with Dr. Donald Billings of High Altitude Observatory, has analyzed spectral-line profiles obtained from prominence observations.

Dr. Layzer and Dr. Krook have developed a simple and powerful method for treating relaxation problems in gases whose molecules repel or attract one another with an inverse-square law of force. The method applies to problems in stellar dynamics and may prove useful in studies of highly ionized gases.

Dr. Krook, Professor Menzel, and Dr. Layzer have jointly investigated magnetic torsional oscillations in the sun and have developed therefrom a semi-quantitative theory of sunspot origin, which accounts for some of the physical properties of sunspots, including their low temperature and magnetic peculiarities. This work formed part of a study of problems

in magnetohydrodynamics. One important conclusion, derived by Dr. Krook and Professor Menzel, relates to the effect of particle density upon the behavior of a gas. Certain equations of magnetohydrodynamics, applicable for high densities, fail to describe the physical picture at lower densities.

Dr. Krook has been studying the dynamics of ionized gases, magnetohydrodynamics, and the theory of stellar atmospheres. He has developed a simplified but accurate procedure for analyzing non-linear steady flow of a gas in one direction. This method provides a unified treatment of such problems over the whole range from continuum flow to free-molecule flow. It also gives insight into the physical state of the gases, including such non-linear conditions as a shock wave. With Dr. E. P. Gross, Dr. Krook has studied the small-amplitude oscillations of an ionized gas in the transition region between low frequencies and high frequencies. He has also devised a new procedure for calculating, with ease and rapidity, the temperature distribution in model stellar atmospheres.

Dr. Layzer attended the Symposium on Fluid Electrodynamics, held by the Royal Society of London in May, 1955. In September, he attended the Symposium on the Formation of Stars, at Glasgow, Scotland, and delivered an invited paper, "Theory for Formation of Astronomical Systems by Gravitational Clustering in an Expanding Universe."

Harvard Radio Astronomy was well represented at the Jodrell Bank Symposium in August, when the discussions included reports of Professor B. J. Bok, Professor D. H. Menzel, Professor F. L. Whipple, Dr. M. Krook, Dr. R. Thomas, Dr. H. I. Ewen, Mr. Thomas A. Matthews, Mr. T. K. Menon, and Mr. Robert Lawrence.

The Harvard Observatory sent a small expedition to Ceylon in the early summer under the sponsorship of Trans-World Airlines and the American Academy of Sciences. The members of the expedition, Dr. William Sinton, Dr. Harold Zirin, and Mr. Owen Gingerich, planned to observe the total eclipse of the sun on June 20. Their program had included a

five-color photometry study of the inner corona, and an additional attempt to detect new infra-red coronal lines. Clouds seriously interfered with the observations and few useful results were obtained.

Dr. Layzer, Professor Menzel, and Dr. Krook are now offering a full course in quantum mechanical foundations, as an expansion of Astronomy 100.

During the past year, Professor Menzel was admitted as a senior member in The Institute of Radio Engineers; elected a member of the American Mathematical Society; elected to foreign associate membership in the Royal Astronomical Society; appointed a member of the Committee on Membership, Class I, Mathematical and Physical Sciences of the American Philosophical Society, 1955–56; made a member of Commission 3 of the International Scientific Radio Union. In May, Professor Menzel was invited to select the recipient of the James H. Rand Scholarship in Astrophysical Computation. A member of the Auroral and Air Glow Panel of the Committee for the International Geophysical Year, Professor Menzel gave the evening lecture at the dedication exercises of the National Bureau of Standards Central Radio Propagation Laboratory, Boulder, Colorado.

Observatory scientists participated in many symposia and conferences both in the United States and abroad. At the meeting of the American Astronomical Society, held at Princeton University Observatory April 3–6, fourteen of the papers presented were those of Harvard staff members. Professor Menzel is President of the Society.

650 astronomers from 41 countries attended the 9th General Assembly of the International Astronomical Union in Dublin, Ireland, August 19–September 5, 1955. The largest delegation of 110 came from the United States, many from Harvard. Professor F. L. Whipple was an official State Department delegate.

Another international meeting was the Symposium on Radio Astronomy, at the Jodrell Bank Experimental Station,

Manchester, England, in August 1955. Many of the papers presented there by the Harvard delegates appear in the bibliography listed in the Appendix of this report. Others will appear in the next annual report, following their publication in a scientific journal.

A large number of papers listed in the Appendix, Section C, are the result of collaborative study. They point up the trend toward more cross-field and joint research, which characterizes much of Harvard's astronomical work. The technics and tools, developed in allied sciences, have many applications to astronomy. We, of the Observatory Council, recognize that great advances are likely to come through the application of these new principles. We have carefully planned our three major programs, embodying studies of the Milky Way, of the sun, and of meteors, so as to make the best use of cross-field developments.

In this report I have merely tried to detail current progress and have barely suggested that long-range aims exist. Although we do have detailed plans, we endeavor to keep them as fluid as possible, so that we may attack whatever problem chances to be most exciting at a given moment. But our broad goal is simply stated. We encounter many unsolved problems as we study the sun, the stars, or other heavenly bodies. We have tried to secure the best observational data possible, by as many technics as possible. One strength of our attack stems from the fact that we employ both visual and radio observations in all three fields listed. Then, applying current theories to our specific problems, we try to determine the precise structure of the individual object under investigation. Our final objective is an understanding of the physical nature of the object, what it is in every detail, and, perhaps, even how it came into being.

Donald H. Menzel
Director

Appendix

PUBLICATIONS FOR THE YEAR 1954–55

A. The Observatory has issued the following regular publications during the year.

Announcement Cards:

Nos. 1275–1313.

Annals:

Vol. 113, Nos. 3, 4.

Reprints:

Nos. 391–419.
Series II, Nos. 66–73.

B. The following Scientific Reports were issued during the year on government contracts for research work at the Observatory.

Contract AF19(604)–146

Scientific Report No. 20, January 6, 1955 — "*A Dynamic Spectrum Analyzer for Sacramento Peak*" — DONALD H. MENZEL, JAMES W. WARWICK, and ROBERT S. LAWRENCE.

S.R. No. 21, April 4, 1955 — "*Magnetic Intensification and the Sunspot Curve of Growth*" — JAMES W. WARWICK.

S.R. No. 22, April 5, 1955 — "*Formation of Absorption Lines*" — JAMES W. WARWICK.

S.R. No. 23, May 9, 1955 — "*Heights of Solar Flares*" — JAMES W. WARWICK.

S.R. No. 24, May 16, 1955 — "*Flare Height and Association with SID's*" — CONSTANCE S. WARWICK.

S.R. No. 25, May 17, 1955 — "*Spin-Orbit Parameters for the p^2 Configuration with Special Reference to the Yellow Coronal Line*" — HAROLD ZIRIN.

S.R. No. 26, July 8, 1955 — "*A Study of 442 Solar Flares Observed at Sacramento Peak, N.M., from 28 February 1951 to 31 October 1953*" — CHING-SUNG YÜ.

S.R. No. 28, August 1, 1955 — *"Energy Levels in the Ground Terms of the Ions A XIII — Ti XVII"* — David Layzer and Harold Zirin.

C. Publications by Observatory Staff Members during 1954–55.

Athay, R. G.

Hydrostatic Equilibrium in the Solar Atmosphere, Journal of Colorado-Wyoming Academy of Science, 1954.

The heliumchromosphere, (Abstract) Astronomical Journal, *60*, 150, 1955.

A model of the chromosphere from 1952 eclipse data, with J.-C. Pecker, R. N. Thomas, and D. H. Menzel, (Abstract) Astronomical Journal, *59*, 314, 1954.

Coronal Line Intensities at the Khartoum Eclipse, with W. O. Roberts, Astrophysical Journal, *121*, 231, 1955.

CN Bands in the Chromosphere, with J.-C. Pecker, Astrophysical Journal, *121*, 391, 1955.

The Thermodynamic State of the Outer Solar Atmosphere. IV. Self-Absorption and the Population of the Second Quantum Level, with R. N. Thomas, Astrophysical Journal, Supplement I, No. 12, 491, 1955.

The Thermodynamic State of the Outer Solar Atmosphere. V. A Model of the Chromosphere from the Continuum Emission, with D. H. Menzel, J.-C. Pecker, and R. N. Thomas, Astrophysical Journal, Supplement I, No. 12, 505, 1955.

Bester, M. J.

See Bok.

Bhatnagar, P. L.

"Turbulence, Kinetic Temperature, and Electron Temperature in Stellar Atmospheres," with M. Krook, D. H. Menzel, and R. N. Thomas, in *Vistas in Astronomy*, edited by A. Beer, Pergamon Press, Ltd., London, 1955.

Bok, B. J.

Radio Studies of Interstellar Hydrogen, Sky and Telescope, *XIII*, 408, 1954.

The New Radio Astronomy, The American Scholar, 449, Autumn 1954.

"The Relative Concentration of Interstellar Hydrogen and Cosmic Dust," in *Les Particles Solides dans les Astres*, Mémoires de la Societé Royale des Sciences de Liége, *XV*, 481, 1955.

Conditions for photoelectric research at the Boyden and Agassiz Stations of Harvard Observatory, (Abstract) Astronomical Journal, *60*, 29, 1955.

Size and type of telescope for a photoelectric observatory, (Abstract) Astronomical Journal, *60*, 31, 1955.

"Seeing" as a factor in the selection of a site for a photoelectric observatory, (Abstract) Astronomical Journal, *60*, 32, 1955.

The New Science of Radio Astronomy, The Scientific Monthly, *80*, 333, 1955.

Gas and Dust in Interstellar Clouds, Astronomical Journal, *60*, 146, 1955.

"Photographic Studies of Southern Emission Nebulae," in *Gas Dynamics of Cosmic Clouds*, International Astronomical Union Symposium Series, Symposium No. 2, Amsterdam, 1955.

"Remarks on the Constancy of the Ratio Between Gas and Dust in Interstellar Matter," in *Gas Dynamics of Cosmic Clouds*, International Astronomical Union Symposium Series, Symposium No. 2, Amsterdam, 1955.

Star Counts for the Section of the Milky Way between Galactic Longitudes 160° and 173°, with J. K. Connolly, S.J., Astronomical Journal, *59*, 384, 1954.

Radio Observations (21 cm) of Dense Dark Nebulae, with R. S. Lawrence and T. K. Menon, Publications of the Astronomical Society of the Pacific, *67*, 108, 1955.

Association of OB Stars and H(II) Regions in the Southern Hemisphere, with C. M. Wade, Publications of the Astronomical Society of the Pacific, *67*, 103, 1955.

Catalogue of H(II) Regions in the Milky Way for Longitudes 250°–335°, with M. J. Bester, and C. M. Wade, Proceedings of the American Academy of Arts and Sciences, *86*, 9, 1955.

"A Preliminary Classification System for Hα Emission Nebulae," with C. M. Wade, in *Gas Dynamics of Cosmic Clouds*, International Astronomical Union Symposium Series, Symposium No. 2, Amsterdam, 1955.

Research of the 21 cm radiation at Agassiz Station, with H. I. Ewen, (Abstract) Astronomical Journal, *59*, 318, 1955.

Bondi, H.

A Note on the Reported Color-Index Effect of Distant Galaxies, with T. Gold and D. W. Sciama, Astrophysical Journal, *120*, 597, 1954.

Connolly, J. K.

See Bok.

Cook, A. F.

The Physical Theory of Meteors. VI. The Light-Curve, Astrophysical Journal, *120*, 572, 1954.

Radiative Equilibrium in a Hydrogen Atmosphere. I., Astrophysical Journal, *120*, 578, 1954.

On the constants of the physical theory of meteors, (Abstract) Astronomical Journal, *60*, 156, 1955.

Photometric Analysis of a Spectrogram of a Perseid Meteor, with P. M. Millman, Astrophysical Journal, *121*, 250, 1955.

Dishong, J.

Nova Sagittarii 1928, HV 12320, with E. D. Hoffleit, Astronomical Journal, *60*, 259, 1955.

Ewen, H. I.

See Bok.

Hearn, A. B.

See Shapley.

Heeschen, D. S.

Investigations of the 21 cm line in the section of the galactic center, (Abstract) Astronomical Journal, *59*, 324, 1954.

Some Features of Interstellar Hydrogen in the Section of the Galactic Center, Astrophysical Journal, *121*, 569, 1955.

Interstellar Hydrogen and the Local System, with A. E. Lilley, Proceedings of the National Academy of Sciences, *40*, 1095, 1954.

An Investigation of the 21-cm Line of Neutral Interstellar Hydrogen in the Section of the Galactic Center, *Thesis*, March, 1955.

HOFFLEIT, E. D.

News Notes, Sky and Telescope (about 80 items a month).

The Long Period Variables in a Field in Sagittarius, American Association of Variable Star Observers, Abstracts, October, 1954.

Book Review: Oscar Lewis, "George Davidson — Pioneer West Coast Scientist," Sky and Telescope, *XIV*, 25, 1954.

"Observational Features in Carina of Interest for Dynamical Theories of Interstellar Clouds and Stellar Evolution," in *Gas Dynamics of Cosmic Clouds*, International Astronomical Union Symposium Series, Symposium No. 2, Amsterdam, 1955.

See also DISHONG.

JACCHIA, L. G.

Measurements of progressive fragmentation in meteors, (Abstract) Astronomical Journal, *60*, 165, 1955.

"On the Numerical Integration of Functions Tabulated in Logarithmic Form," in Mathematical Tables and Other Aids to Computation, *IX*, No. 50, 63, 1955.

The Physical Theory of Meteors. VIII. Fragmentation as a Cause of the Faint-Meteor Anomaly, Astrophysical Journal, *121*, 521, 1955.

See also WRIGHT.

KROOK, M.

Mechanisms in prominence activity, with D. Layzer and D. H. Menzel, (Abstract) Astronomical Journal, *60*, 166, 1955.

See also BHATNAGAR, MENZEL.

LAWRENCE, R. S.

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STEWARD OBSERVATORY

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STEWARD OBSERVATOR

Harvard College Observatory

To the Dean of the Faculty of Arts and Sciences:

Sir, — The Harvard College Observatory Council, consisting of Professor Bart J. Bok, Professor Cecilia Payne-Gaposchkin, Professor Fred L. Whipple, Dr. Richard N. Thomas, Dr. Gerhard R. Miczaika, and myself, Professor Donald H. Menzel, take pleasure in submitting this annual report for the year 1955–56.

On May 7, 1956, Dr. Cecilia Payne-Gaposchkin was appointed Professor of Astronomy. Dr. Harlow Shapley became Paine Professor of Practical Astronomy Emeritus in June, 1956.

On March 19, 1956, Dr. Donald H. Menzel was appointed Paine Professor of Practical Astronomy, and Professor of Astrophysics. Professor Bart J. Bok, whose resignation was announced on May 10, 1956, will leave Cambridge in January, 1957, to assume his duties as Director of the Commonwealth Observatory at Canberra, and Professor of Astronomy in the Research School of Physical Sciences, Australian National University. Dr. Dorrit Hoffleit also resigned, to take up work at Yale University Observatory and at the Maria Mitchell Observatory, Nantucket, Mass. Miss Arville D. Walker and Miss Madeleine E. Harvey retired this year.

Mrs. Velma A. Adams, administrative assistant to the Director, resigned after five years with the Observatory. Mrs. Helen S. Federer, formerly managing editor of *Sky and Telescope*, is the new administrative assistant.

Dr. Anne B. Underhill, of the Dominion Astrophysical Observatory, Victoria, British Columbia, spent the year here as a Research Associate and Visiting Lecturer. Dr. A. G. Velghe continued as a Research Fellow. Mr. George Field, a Junior Fellow at Harvard, is at the Observatory.

The renovation of the old Gray Herbarium, now called Kittredge Hall, across Garden Street from the Observatory, is virtually complete. Members of the Smithsonian Astrophysical Observatory and some of our own personnel will occupy offices this building provides. For the present, therefore, we have fairly adequate space, but the need still remains for an additional building on the Observatory grounds, for fully efficient present operation and to permit future expansion.

The urgent need still exists for a modern and well-equipped machine shop on the grounds in Cambridge.

Miss Frances W. Wright continues as Executive Secretary in the Department of Astronomy, of which Dr. Fred L. Whipple is Chairman. Sixteen graduate students were in residence during the academic year, and three others were working on their theses while employed elsewhere. Eight students received their doctoral degrees during 1956, the largest number on record for our Department. Arthur E. Lilley, Richard E. McCrosky, Frank Q. Orrall, Elske van Panhuys Smith, and Henry J. Smith received their degrees in March, while Franklin E. Kameny, Thomas A. Matthews, and Thuppalay K. Menon received degrees in June.

Three graduate students this year, Robert J. Davis, Frank D. Drake, and Andrew T. Young, were National Science Foundation Fellows. Dr. Dennis W. Sciama had an Agassiz Fellowship. A Pickering Fellowship was held by Mrs. Nannielou Dieter.

We have made important progress toward the development of a long-range, stable solution to the problem of administering and making effective use of the Boyden Observatory, in Bloemfontein, South Africa, as the former Harvard station is now known. Tentative plans call for the establishment of a separate corporation, having its own capital funds, authorized to receive gifts and to own or lease property. The corporation will consist of six members, Harvard College Observatory, U. S. A.; Armagh Observatory, Northern Ireland; Dunsink Observatory, Eire; Swedish Astronomical Observatories; German Astronomical Observatories; and Belgian Astronomical Observatories. Although

more than one Swedish, German, or Belgian observatory may take part in operating the station, each country participates as a unit. The costs of operation are to be shared on an agreed-upon basis among the five members other than Harvard, Harvard's original investment standing as its basic share. The members will share special costs, on a basis to be agreed upon. All members of the Administrative Council of the Boyden Observatory, who met May 11–12, 1956, at Bonn, Germany, concurred in this arrangement. Dr. Menzel continues as Chairman of that Council.

This year saw the completion of the renovation and conversion of the Rotunda into the George R. Agassiz Memorial Room. An anonymous benefactor contributed substantially to this Observatory project. An informal dedication took place on April 13, 1956, in conjunction with the annual inspection of the Harvard College Observatory Visiting Committee. The new exhibits include a model showing the phases of the moon, painted by the well-known artist, Capt. Charles Bittinger; two murals painted by Dr. Sergei Gaposchkin, one of the solar system and the other to provide a background for the model of the proposed artificial satellite, built and donated by Baird Associates; a model of the 60-foot radio telescope at Agassiz Station, both the model and the original built by the D. S. Kennedy Company; and a number of large transparencies. This stimulating and exciting exhibit room attracts considerable interest from students and our many visitors, and contributes greatly to Open Night programs.

The new 60-foot radio telescope — the largest to date in America — was dedicated on April 28th at the George R. Agassiz Station. Professor Bart J. Bok, co-director of Harvard's radio astronomy project, presided at this first public detailed discussion of the new telescope. The instrument's design and mechanics were described by Robert J. Grenzeback, chief engineer of D. S. Kennedy Company, Cohasset, the builders. Dr. Harold I. Ewen, co-director of the radio astronomy project, discussed the telescope's electronic components, built by the Ewen Knight Corporation, of Needham.

The dedication itself took place at 11 a.m., with President Nathan M. Pusey as a speaker, and Dr. Menzel presiding. Dr. Alan T. Waterman, director of the National Science Foundation, dedicated the instrument. The Foundation provided the principal financial support for its construction. Other speakers were Dr. Lloyd V. Berkner, president of Associated Universities, Inc., which operates the Brookhaven National Laboratories, and Dr. John P. Hagen, of the Naval Research Laboratory, who is director of Project Vanguard, the artificial satellite program of the United States. An oak plaque commemorating George R. Agassiz was unveiled in the laboratory building. Following the dedication ceremony, a buffet lunch was served.

A brief symposium took place in the afternoon, to discuss past, present, and future 21-centimeter research, which started in 1951 when Dr. Ewen and Dr. Edward M. Purcell, of Harvard, first detected the radio emissions of neutral hydrogen from outer space. Speakers were Dr. David S. Heeschen, Agassiz Radio Astronomer at Harvard and Dr. Edward F. McClain, of the Naval Research Laboratory. Dr. Heeschen holds one of the first two Ph.D. degrees awarded by Harvard in radio astronomy.

The Agassiz radio project continues to emphasize related radio and optical studies of sections of the Milky Way and objects of special interest. It is substantially supported by the National Science Foundation, by grants from the American Academy of Arts and Sciences, and by anonymous gifts.

Construction of the 60-foot radio telescope is virtually completed. It will go into preliminary operation with the electronic equipment previously attached to the 24-foot radio telescope. The gift of an analog-to-digital computer from the Consolidated Electrodynamics Corporation, of Pasadena, California, through Mr. Philip Fogg, is gratefully acknowledged. The unit comprises a modern and efficient data-recording system.

The principal research projects recently completed or now in progress are:

1. Studies of the neutral atomic hydrogen content of optically known gas and dust clouds of our galaxy.

2. Detailed studies of the spiral structure of some sections of the Milky Way, notably those between galactic longitude 60° and 110° and between 335° and 15°; also a study of the Cygnus complex.

3. Studies of 21-centimeter radiation from star clusters and stellar associations.

4. A comprehensive study of the Orion aggregate, including the associations NGC 2244, NGC 2264, and Lambda Orionis.

5. The discovery and study of 21-centimeter emission from the Coma cluster of galaxies, shifted in frequency as predicted from the optically observed radial velocity of recession.

The Harvard radio astronomers have learned much that is new about the fine structure of the interstellar medium of neutral hydrogen atoms. Quite recently Dr. Heeschen has detected 21-centimeter radiation reaching us from the very distant cluster of galaxies in the constellation of Coma Berenices. Dr. T. K. Menon's work on the neutral hydrogen content of the Orion Nebula and its surroundings is proving to be of considerable importance for cosmological studies of stellar evolution. Once the 60-footer and its new electronic equipment are in full-scale operation, special attention will be given to studies of absorption features and to further research into the 21-centimeter radiation from beyond our own Milky Way system.

Papers were presented at the Troy meeting of the American Astronomical Society concerning problems in radio astronomy by D. S. Heeschen and F. D. Drake; by W. E. Howard, III, and D. S. Heeschen; and by T. K. Menon. Mrs. May Kassim and Campbell M. Wade were also active in the radio astronomy project during the year.

Under the direction of Dr. Gerhard R. Miczaika, Astronomer-in-Charge of the Agassiz Station, the general program of rehabilitation has continued. The work on the 24-inch reflector has been completed. A new photoelectric photometer employed at the Cassegrain focus of the telescope was installed. Its light detector is a 1P21 photomultiplier. The telescope is now being used for photoelectric work with this photometer or with a newly developed photometer for the infrared. The new aluminizing plant attached to the 61-inch building has been frequently used

for coating mirrors of our own instruments and for other institutions in the area.

Rehabilitation of the 61-inch reflector approaches completion. The new mirror cell with the support system has been delivered and installed. We also obtained the carriage for lifting the mirror with its cell into its proper position at the tube of the telescope; the carriage also transports the mirror and cell into the aluminizing room, where a special hoist enables the operator to separate the mirror from the cell and put it into the vacuum chamber.

The new drive in declination has been obtained and installed. Delivery of the right-ascension drive is expected toward the end of November. The telescope has been put into temporary working condition with the old right-ascension drive to enable Dr. William M. Sinton to execute his Mars program during this fall.

The roof of the 61-inch dome has undergone thorough repair, and the inside of the dome and building as well as the telescope itself have been painted.

No progress has been made with the construction of the proposed grating spectrograph for the Cassegrain focus of the 61-inch reflector, because of lack of funds.

Mr. David Keren has succeeded Mr. Jack Campbell in the construction and maintenance of electronic parts of the optical telescopes at Agassiz. Mr. Lionel Caron has again made many of the necessary parts for the rehabilitation work, using the old shop in Cambridge. He also carried the additional load of the mechanical maintenance of the instruments in Cambridge and at Agassiz. The new small shop at the Station has proven very useful, and we again enjoyed the co-operation of the Gordon McKay Laboratory shop.

Beyond all this, extensive work has been done on the buildings and grounds at the Station.

The electronic laboratory in Cambridge was occupied with the construction of components for telescopes at Agassiz Station. A group working on Dr. Fred L. Whipple's meteor proj-

ects also used the laboratory facilities to construct electronic equipment to be employed for radio meteor observations.

Dr. Miczaika and Miss Mary Jane Stewart have pursued an analysis of turbulent motions in the atmosphere of the metallic line star 8 Comae. Dr. Miczaika and Mr. Frank Drake, in collaboration with Mr. Donald J. Lovell from the Allied Research Corporation in Boston, are developing a new technique for stellar photometry in the infrared. This investigation is being supported in part by a grant from the American Academy of Arts and Sciences.

Mrs. Cecilia Payne-Gaposchkin has devoted most of her time to the completion of a monograph on the galactic novae, which will be published in the near future. She spent three weeks during the spring at the Lick Observatory, Mount Hamilton, California, studying the spectra of novae, and is now working on a systematic analysis of the spectra of Nova Herculis, Nova Pictoris, Nova Lacertae, and Nova Puppis. In May, 1956, Mrs. Gaposchkin was elected an Associate of the Royal Astronomical Society.

Dr. Sergei Gaposchkin has carried on his studies of eclipsing variables. He has also completed the work on variable stars in Messier 31 which he undertook as a guest investigator at Mount Wilson and Palomar Observatories. He leaves for Australia this July, under a grant from the National Science Foundation, to spend a year in studying the spectra of bright southern stars at the Commonwealth Observatory, Mount Stromlo.

Last July, Miss Margaret Olmsted prepared a 23-page mimeographed progress report on the work done by herself and other assistants for the last five years under the direction of Dr. Bart J. Bok.

Dr. David Layzer developed a new statistical model for the spatial distribution of galaxies. This work forms part of a continuing program, initiated by Dr. Layzer in 1952, to develop, on the basis of Einstein's theory of gravitation, a statistical theory for the origin and evolution of self-gravitating astronomical systems.

Dr. A. G. Velghe made a study of dark nebulae based on trun-

cated distributions of stars, resulting in a new method of analysis of counts in star clusters with small dispersion in absolute magnitude. Another investigation concerned the application of data from low-dispersion spectra in the yellow-red region to problems of galactic research.

Dr. William M. Sinton, since the first of the year, has been developing equipment for infrared observations of the planet Mars at its close approach in the fall of 1956, to test the hypothesis that vegetation exists on Mars, by detection of absorption bands of chlorophyll.

Dr. Richard N. Thomas has been appointed a non-resident tutor at Leverett House.

Professor Fred L. Whipple has continued as Professor of Astronomy at Harvard and member of the Harvard College Observatory Council. As Director of the Smithsonian Astrophysical Observatory he has devoted himself to furthering an intimate association between Harvard College Observatory and Smithsonian, and to the development of the optical tracking programs for the artificial earth satellite project of the National Academy of Sciences, for the International Geophysical Year. Professor Whipple was elected President of the International Astronomical Union's Subcommittee 22 on Meteoritics.

Dr. Richard E. McCrosky, in his research under a contract with the U. S. Office of Naval Research, has continued to employ a rapid reduction method for photographic meteor trails, and has investigated the meteor "wake," the luminosity that follows the head of a meteor.

The meteor project sponsored by U. S. Air Force Contract AF 19(122)–482 has continued to operate the meteor observing stations at Sunspot and Mayhill, in New Mexico. The observing program, carried out with the Baker super-Schmidt cameras, resulted in photographing approximately 630 double-station meteor trails through February, 1956. Mr. Gunther Schwartz is the Observer-in-Charge in New Mexico.

The equipment has also been utilized to photograph a number

of special rocket flights from nearby Holloman Air Force Base which required the unique characteristics of the meteor cameras. Among these was the flight of March 14, 1956, designed to study the luminescence of nitric oxide introduced into the upper atmosphere. The time-lapse photographs of the gas cloud are being analyzed by Dr. Allan F. Cook and Mr. Andrew Young to determine the decay mechanism of the process.

Dr. Whipple has shown how an extremely low density (about 0.05 gm/cm^3) for visual and fainter meteoroids will bring into agreement various data and deductions that now appear discordant. The new value is consistent with the total influx of meteoritic material on the earth, which is correspondingly increased by two orders of magnitude.

Dr. Cook has continued to supervise the meteor train reductions, under the Air Force meteor contract, carried out by Mr. Robert F. Hughes and Mr. Richard Rodman for the determination of winds in the upper atmosphere. The results of this work, combined with older visual observations available in the literature, have led Dr. Cook and Dr. Whipple to a study of the turbulence field in the upper atmosphere and the winds driving the turbulence.

Dr. Cook and Dr. Gerald S. Hawkins have studied meteoric ions and electrons as a possible source of radiation through recombination in persistent meteoric trains.

Dr. Cook and Dr. Peter M. Millman, of the Dominion Observatory, Ottawa, and the National Research Council of Canada, have continued their spectrophotometric study of a slow meteor photographed at the western stations of the Dominion Observatory.

Miss Frances W. Wright has carried forward the analysis of the radiant motion and scatter for the Iota Aquarid meteor stream. To help in the analysis of meteors and meteorites, she has translated several papers from Russian into English; mimeographed copies are available.

Dr. Richard N. Thomas carried on further investigations of

the physical theory of meteors, with special attention to the problem of pitting on the meteor surface.

The reduction of super-Schmidt meteors by highly accurate techniques has continued under the direction of Dr. Luigi Jacchia, supported by the U. S. Army Office of Ordnance Research. Most of the actual computations in this program are performed in New York by Mr. Robert E. Briggs and Mr. John J. Murphy on a "650" calculator of the Watson Scientific Laboratories of the International Business Machines Corporation, whose generous support of this project is gratefully acknowledged. The detailed methods of reduction are now in press, in the Smithsonian Contributions to Astrophysics.

Dr. Jacchia has continued his research on meteor decelerations as related to the physical structure of meteors and to problems of the upper atmosphere. A preliminary analysis of the atmospheric densities computed from meteor decelerations was made by Dr. Jacchia on the basis of all the super-Schmidt material available in July, 1955 (178 meteors), to investigate the existence of detectable oscillations with periods (and half periods) corresponding to those of solar and lunar tides, and with seasonal variations.

During this past year, a research program has been carried out with the support of the Lincoln Laboratory under the direction of Dr. Gerald S. Hawkins. Associated in the research was Dr. Curtis L. Hemenway, on a year's sabbatical leave from the Department of Physics at Union College. Mr. Martin L. Shapiro, a radio engineer, has joined the group in the past year. From the radar data collected at Manchester, England, Dr. Hawkins has made a preliminary estimate of the direction and rate of arrival of sporadic meteors. These results have been augmented by the 200 photographic meteors analyzed by the short-trail method.

In the field of meteor physics, Drs. Cook and Hawkins have studied the nature of the ball of ionization that radar observers have detected near large meteors. Dr. Hawkins has also established a relation between the brightness of a meteor and its electron line density, and has confirmed the marked dependence of

the ionization probability on meteor velocity. Drs. Hemenway and Hawkins have begun studies to see whether meteors produce magnetic pulses and radio noise. In the field of meteor geophysics, Drs. Whipple and Hawkins have examined the current suggestion that meteor dust is the cause of heavy rainfalls, and concluded that the theory is consistent only if micrometeorites are destroyed by the etching process of corpuscular radiation from the sun.

Members of the radio meteor research program have attended meetings of the American Astronomical Society, in Columbus, Ohio, and Troy, New York, and the URSI meeting in Washington in May, 1956. They have conferred with radio astronomers in Manchester, England; Ottawa, Canada; Boulder, Colorado; and Palo Alto, California.

Investigations of problems of solar astronomy continued actively, under support of Air Force contracts.

Dr. Donald H. Menzel, Dr. Max Krook, and Dr. David Layzer continued studies of general problems of magnetohydrodynamics. Drs. Menzel and Krook examined various possibilities for the production of low-energy cosmic radiation within the outer layers of the sun; qualitative analysis indicates that magnetohydrodynamic shock waves may be a potential source. Another investigation concerned the influence of magnetic fields on the production of turbulence in the neighborhood of sunspots. The problem is one of convective transport of energy and includes the basic processes of corona formation and the propagation of shock waves through the corona.

Dr. Menzel, Mr. Harold Glazer, and Mr. John Wolbach have completed a statistical analysis of the E layer of the ionosphere, based on all available ionospheric data on a worldwide basis. The results yield an excellent representation of the electron density within that layer, as a function of time of day, time of year, position on the earth's surface, and phases of the sunspot cycle. The F_2 layer, much more complex than either the E or F_1 layers, is under investigation by the same techniques. Analysis by means

of IBM punched cards is going forward. Dr. Menzel has studied the theoretical development of the formation of the E layer as a result of ionizing radiation from the sun, for a polytropic atmosphere.

On April 26, 1956, Dr. Menzel gave the James Arthur Lecture for the Smithsonian Institution, entitled "The Edge of the Sun."

Statistical studies of sunspot properties by Dr. Barbara Bell, with Mr. Glazer, involving the relation of sunspot magnetic class and spot area with geomagnetic activity, reveal that magnetic class is a very important criterion for predicting the geomagnetic effects of a specific spot group.

Dr. Krook has constructed a dynamical model of the solar atmosphere that appears capable of giving a unified account of the various fine-structure phenomena in the outer layers of the sun. The model has definite implications for the formation of the continuous and line spectra. In another investigation, he has found it possible to obtain exact numerical solutions of the Bhatnagar-Gross-Krook kinetic equation without excessive labor, for several one-dimensional, steady-state flow problems of gas dynamics.

A detailed classification based on motion picture films and "still" surveys made at Climax, Colorado, and on Sacramento Peak is being carried out by Dr. F. Shirley Jones, working with Dr. Menzel, according to the Menzel-Evans classification scheme.

The research program aimed at an investigation of the structure of the outer solar atmosphere, under the direction of Dr. Richard N. Thomas, continued to progress from three aspects: continuation of the analysis of eclipse observations; the beginning of an analysis of the data from the high-resolution instruments of Sacramento Peak Observatory, now coming into continuous operation; some purely theoretical work aimed at laying an analytical basis for other phases of the work.

The preliminary analysis of the 1952 eclipse data largely drew to a close this year. This work has been a co-operative effort among personnel of the Harvard Observatory, High Altitude Observatory, and Sacramento Peak Observatory. Three investi-

gations started during the preceding year have been completed and published this year: an investigation of the non-uniform structure of the chromosphere by analyzing jointly observations of hydrogen and helium, by Drs. Menzel and R. G. Athay; an analysis of the structure of the chromosphere from the standpoint of thermal stability, by Drs. Athay and Thomas; and a comparative analysis of several chromospheric models and the question of chromospheric variability, also by Drs. Athay and Thomas. This last aspect of comparing chromospheric observations from various eclipses, by a remeasure and rediscussion of data from the 1932, 1936, and 1952 eclipses, has been further investigated by Drs. Athay, Menzel, and Frank Q. Orrall. Finally, the last major set of data remaining in the 1952 observations, that on the metallic spectrum, has been measured, reduced, and discussed for his Ph.D. thesis by Mr. Jack Zirker. Mr. Zirker will continue this work on the metallic lines, utilizing the Sacramento Peak equipment, when he joins the staff there.

Planning has begun for observing the 1958 eclipse and the 1959 eclipse, under a program directed by the Sacramento Peak Observatory.

A series of investigations has been initiated on the behavior of the hydrogen lines H-alpha to H-10 in the solar atmosphere. This program involves the eclipse data, various investigations of the hydrogen lines on the disk, and observations with the 16-inch coronagraph at the solar limb. An analysis of the behavior of Lyman-alpha, aimed at interpreting rocket observations of this line, has been completed by Drs. Athay and Thomas. A similar program for the early Balmer lines is under way. Eclipse, disk, and coronagraph observations have been combined by Drs. Athay and Thomas to obtain a preliminary model of the behavior of the early Balmer lines in the solar atmosphere. A systematic program of investigations of these lines with the 16-inch coronagraph has been initiated by Dr. Elske v. P. Smith on Sacramento Peak, and Drs. Athay and Thomas.

The structure of spicules and prominences continues as a subject of inquiry. Investigations of the structure of prominences,

based on studies of patrol films, monochromatic filter observations, and data obtained at eclipses, reported in previous years by Dr. Orrall, has been synthesized in his Ph.D. thesis. Dr. Athay and Dr. Orrall have carried out further studies of the structure of prominences. A systematic program of reduction and analysis of several years' observations of spicules has been commenced by Mr. Richard B. Dunn, of the Sacramento Peak staff. Drs. Athay and Thomas have discussed preliminary results from this analysis, in terms of the relations of spicules to the structure of the chromosphere.

Dr. Henry J. Smith, Astronomer-in-Charge at Sacramento Peak, is employing the 16-inch coronagraph to inquire into the general spectrum of the upper photosphere and lower chromosphere. Dr. Thomas is pursuing an accompanying theoretical investigation of the mechanism of formation of spectral lines in these atmospheric regions.

The patrol program continued to improve in instrumentation and in increase of standards of photometry. The prominence camera has been fitted with a new objective of coronagraph quality, a new dust tube, a new focus control and occulting system, and refined adjustments for the secondary optical system. The remainder of the f/60 spectrograph was installed, but a secondary guider and image rotating prism and the pre-filter monochromator for the spectrograph are still needed. The universal f/30 spectrograph and the Lyot filter cinematograph are completed. The latter is being used by Dr. Elske Smith, in a joint project with Dr. Henry Smith, for a chromospheric flare patrol program and, with the universal spectrograph, for flare spectra. They obtained the first H-alpha time sequence spectrogram of a solar flare using a 35-mm. cine camera on the large spectrograph.

Dr. Henry Smith participated in the planning and designing of instrumental improvements including adoption of the prominence camera for the surge patrol program, automatic time recording on the cine films, and accessories for the large Littrow spectrograph.

The systematic surge patrol began continuous operation last

fall, and routine in-focus patrol observations of red and green coronal lines were made. The surge patrol operated for three months, and then was discontinued until the more convenient one-shot prominence camera becomes available. The coronal patrol observations are now given in absolute intensities so that the records for Sacramento Peak and Climax are on a homogeneous basis. A program of movies of active plages is being included with the flare patrol, on days of good seeing, when there is promise of flares.

The Harvard observers, working with Mr. Dunn, of the Sacramento Peak Observatory, made the first successful direct photograph of the green coronal line with the 6-inch coronagraph and a birefringent filter. Surveys are now made on every suitable day, and motion picture sequences when sky conditions permit.

At the Peak, Mr. Harry E. Ramsey is Observer-in-Charge, and Mr. George K. Schnable is Optical Engineer.

Dr. John W. Evans, Superintendent of the Sacramento Peak Observatory, has developed a photoelectric coronameter. This device eliminates electronically the overwhelming influence of atmospheric and instrumental scattered light which otherwise drowns out the relatively feeble corona. The coronameter is not in routine patrol operation. Dr. Evans is instead trying to observe coronal lines to fainter limits than have hitherto been attained. The instrument is very successful with the green line where the photomultiplier is most efficient; results for the yellow line are as yet ambiguous.

Dr. Thomas delivered the opening address at the Conference on Solar Energy — the Scientific Basis, of the World Symposium on Solar Energy at Tucson and Phoenix, Arizona; he discussed the relation of astronomical investigations of solar radiation to the problem of the utilization of solar energy. At a symposium on the structure of the outer solar atmosphere, held at the American Astronomical Society meeting in Troy, New York, last November, Dr. Evans discussed the observational, and Dr. Thomas the analytical, aspects of eclipse and coronagraphic studies. Papers on particular aspects of the investigations of prominences, spicules,

the coronal lines, and the spectrum of the chromosphere obtained by the 16-inch coronagraph were given at the Troy and at the Berkeley AAS meetings by Athay, Evans, Dunn, Orrall, E. v. P. Smith, Henry Smith, and Thomas. Dr. Thomas presented a summary of the solar program in these aspects, concerning work of the co-operating Harvard, High Altitude, and Sacramento Peak observatories, at a solar symposium at the Solar Observatory in Utrecht, this summer.

The exchange program among the staff at these three American observatories has continued to prosper. Dr. Athay spent this past year at Harvard and on Sacramento Peak. Drs. James and Constance Warwick, also from High Altitude Observatory, have been on the Peak. Dr. Thomas has spent several short periods at High Altitude and at the Peak, and one extended period at the latter. Dr. Menzel has made several trips to the Western observatories.

Dr. William M. Sinton, of Harvard, was on a leave of absence during the summer and fall of 1955 to carry out solar research at Sacramento Peak. He completed the adjustments of the large spectrograph of the 16-inch coronagraph and with this instrument made observations of the magnetic fields of sunspots. In addition, he obtained high-dispersion spectra of Venus and of several bright stars.

The solar radio program, supported by a contract with the Air Force, has been actively pursued, with Dr. Alan Maxwell as Astronomer-in-Charge of the Radio Astronomy Station, assisted by Mr. Samuel J. Goldstein. The equipment could not be located at the Sacramento Peak Observatory, as was planned last year, because the extremely undesirable interference there would have rendered the radio observations useless. Therefore it was necessary to seek a suitable location, and then to negotiate and plan for the construction of a new station. The site finally chosen is near Fort Davis, Texas, a fortunate choice because it combines a virtually noise-free location with reasonable proximity to Sacramento Peak (about 350 miles) and closeness to another center

of astronomical activity, the McDonald Observatory of the Universities of Chicago and Texas.

Meanwhile, construction of the equipment proceeded. The 28-foot paraboloid antenna, equatorially mounted, and provided with servo-control mechanism, was fabricated by D. S. Kennedy Company, of Cohasset, Mass. The figure of the reflector surface will be accurate to 3/8 inch under windloading conditions of 40 miles per hour. The antenna, consisting of six aluminum sections, will be mounted so as to cover the entire sky. The mount is to be a prefabricated steel tower. The mount and drive assembly were tested on the tower in the Kennedy factory in February.

The antenna feeds consist of three primary arrays at the focus of the paraboloid: two broad-band dipoles and reflectors, cross polarized, for the low and middle frequency bands of the spectrum analyzer, and a horn for the high-frequency band. Dr. Henry Jasik, of Mineola, New York, designed the feeds. The frequency ranges on the feeds and their associated receivers will be 90–180, 160–320, and 300–600 mc/sec.

The three receivers, built by Airborne Instruments Laboratory, Mineola, New York, have bandwidths of 0.3, 0.5, and 1.0 mc/sec. High-resolution cathode-ray tubes are being used in the display units, for optimum operating efficiency of the spectrum analyzer, with a time resolution of one-tenth of a second. Data are recorded photographically by a Fairchild camera with a modified lens and a mounting hood.

By late spring, the component parts of the equipment had been completed and tested in the East, and shipped to Texas, and plans for construction of the laboratory building at the site were concluded.

Dr. Maxwell and Mr. Goldstein moved to Fort Davis in May, to supervise erection of equipment at the new Radio Astronomy Station. The concrete pier for the antenna and tower was built in June.

The large aperture of the antenna and the high sensitivity of the receivers should yield interesting results for radio sources in

the solar atmosphere. With continuation of the Air Force contract under which this solar radio work is being carried out, we look forward to interesting amplification of our already active solar research program.

A conference on "The Effects of the Earth's Atmosphere on Radio Waves from Outer Space" was held at the Observatory in Cambridge on May 10, 1956, arranged by Dr. Maxwell. About 40 representatives of institutions and corporations attended. Present and proposed ionospheric research programs in the United States that use radio astronomy techniques, and instrumentation problems, were discussed.

In addition to the gifts already specifically mentioned in this report, we gratefully acknowledge a grant from Trans World Airlines in support of the solar eclipse research project; gifts from various anonymous donors; and gifts from Thomas C. Desmond, the Estate of Charles W. Elmer, Dr. Marion Eppley, Mrs. Marion Eppley, the Higgins Trust, and John G. Wolbach.

In this report I have tried to stress scientific accomplishment rather than details of administration. The breadth and depth of the researches continue to increase. The improved visual instrumentation and the new 60-foot radio telescope at the Agassiz Station markedly augment the observational equipment available for research of students and staff. The Radio Astronomy Station at Fort Davis, Texas, provides us with means for a new attack on solar problems. The advanced visual equipment on Sacramento Peak is giving results of high quality, as the more complex accessories go into operation.

The association between Harvard College Observatory and the Smithsonian Astrophysical Observatory, referred to in my previous report, has now been in operation a full year. The directors agree that the association has greatly benefited both organizations. The over-all enhancement of scientific activity in the Smithsonian has served to stimulate parallel studies and collaborative effort within the Harvard group.

As in recent years, the trend toward cross-field studies and joint research has accelerated. The years of planning and developing the basic observational equipment for such programs are beginning to pay dividends in the form of new data and new theories.

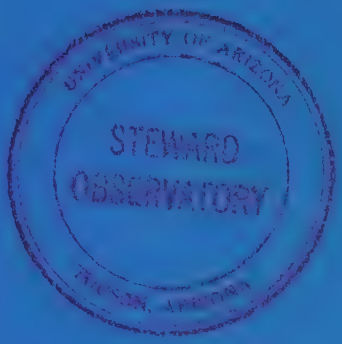
Donald H. Menzel
Director

PUBLICATIONS FOR THE YEAR 1955–56

Members of the Observatory staff published some 72 papers in various scientific journals. Twenty scientific reports were issued on government contracts for research work at the Observatory. The complete list of publications may be found in the Harvard College Observatory Director's Report (hectographed), 1955–56.

HARVARD
ASTRONOMICAL OBSERVATORY

ANNUAL REPORT



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Harvard College Observatory

To the Dean of the Faculty of Arts and Sciences:

Sir, — The Harvard College Observatory Council, consisting of Professors Cecilia Payne-Gaposchkin, Thomas Gold, Theodore E. Sterne, and Fred L. Whipple, Dr. Gerhard R. Miczaika, and myself, Professor Donald H. Menzel, take pleasure in submitting this annual report for the year 1956–57.

The appointment of Dr. Sterne as Simon Newcomb Professor of Astrophysics became effective this year; he is also Associate Director of the Smithsonian Astrophysical Observatory. Dr. Gold, formerly Chief Assistant to the Astronomer Royal in England, came to Harvard in February as Professor of Astronomy.

Professor Bart J. Bok left Cambridge in January, 1957, to become director of the Commonwealth Observatory at Canberra, Australia. Dr. Richard N. Thomas, formerly Lecturer and Research Associate, is now at the National Bureau of Standards, Boulder, Colorado.

A record-breaking number of members attended the American Astronomical Society's 97th meeting held here in May, 1957. Harvard College Observatory and the Smithsonian Astrophysical Observatory were joint hosts. As retiring President, Dr. Menzel gave an address, "The Nature of the Solar Corona," in which he summarized the observational work of recent years, and described a detailed theoretical interpretation of solar phenomena. A 35-mm film prepared from selected Sacramento Peak solar observations illustrated the lecture.

"Astronomers Look at Space Travel," a public panel discussion sponsored by the AAS Committee on Education, attracted a near-capacity crowd to Harvard's Sanders Theatre. An Open House at the George R. Agassiz Station in Harvard, Massachusetts, allowed many visiting astronomers to inspect the optical

and radio telescopes and to see some of our newer equipment for the first time.

The two host organizations and the National Science Foundation jointly sponsored a scientific conference on "The Scale of the Galaxy," under the direction of Dr. Harold F. Weaver, of the University of California, who was spending a year's leave at Harvard Observatory as a Guggenheim Fellow. Following the conference, Dr. D. W. N. Stibbs, of The Observatory, Oxford, England, one of the participants, spent several weeks here and at other American and Canadian observatories.

The Third International Symposium on Cosmical Gas Dynamics took place at the Observatory on June 24–29, 1957. Organized by committees from the International Astronomical Union and the International Union of Theoretical and Applied Mechanics, the symposium was sponsored by the Smithsonian Astrophysical Observatory and the U. S. Air Force. Dr. Richard N. Thomas served as secretary. More than 100 scientists from seven countries attended this meeting.

The Phillips Library in Cambridge contained 9,610 bound volumes and papers at the close of June, 1957, a net increase of 180 in the past year. Mrs. Ilene Guttmacher is librarian, and Dr. Joseph Ashbrook continues as chairman of the library committee. The George R. Agassiz Station Library acquired 15 additional bound periodicals, bringing this active reference and working library at the Station to a total of approximately 500 volumes.

We continue our custom of offering a series of Open Nights each fall, spring, and summer. We encourage those interested, particularly the children, to visit the Observatory on the scheduled dates when we provide illustrated lectures, guided tours, and an opportunity to look through telescopes. Miss Frances W. Wright again took charge of regular Open Nights, for which more than 2,000 visitors applied for tickets. Miss Margaret Olmsted arranged the 1956 summer Open Night. Professor Bart J. Bok, Mr. Frank D. Drake, Dr. Gerald S. Hawkins, Professor Donald H. Menzel, and Dr. William M. Sinton all gave lectures at the Open

Nights. The George R. Agassiz Memorial Room of astronomical exhibits proved a great attraction for our many visitors.

Professor Cecilia Payne-Gaposchkin has succeeded Dr. Fred L. Whipple as Chairman of the Department of Astronomy. Miss Frances W. Wright continues as Executive Secretary of the Department. Eighteen graduate students were in residence during the academic year, and two others were working on their theses while employed elsewhere. One student, Jack Bernard Zirker, received a doctor's degree in March of 1957. Two graduate students, Robert J. Davis and Frank D. Drake, held General Electric Fellowships; two, Fred A. Franklin and William E. Howard, III, received Agassiz Fellowships, and Carlos M. Varsavsky had an Elmer Scholarship and a Fellowship under the Harvard Faculty of Arts and Sciences. A Pickering Fellowship and a Radcliffe Fellowship were held by Mrs. Nannielou Dieter. Most of the other graduate students were part-time teaching fellows or research assistants.

Dr. Payne-Gaposchkin has continued her researches on the spectra of novae. She secured the observational material during visits to Lick Observatory and Mount Wilson Observatory a year ago, and the subsequent work has been supported by a grant from the Milton Fund. During the past two years, a major project has been the preparation of her book, *The Galactic Novae*, issued by the North Holland Publishing Company during the summer of 1957.

At the International Astrophysics Conference at Liège in July, 1957, she delivered an invited address on "Relationships between Variable Stars with Bright Lines," which embodies much of her recent work on the subject. Dr. Payne-Gaposchkin is a member of the Advisory Panel on Astronomy to the National Science Foundation.

From a theoretical study of turbulence in the ionosphere, Dr. David Layzer has developed a new interpretation of the so-called Richardson number, a quantity of importance in meteorology and in the theory of rotating stars. The study has led to a new esti-

mate for the rate of turbulent dissipation in the ionosphere, differing by several orders of magnitude from that given by Booker of Cornell, and applies to the structure of meteor trails as well.

Dr. Layzer's work on the theory of complex atomic spectra brings nearly to completion a study begun seven years ago. This new approach provides a theoretical basis for predicting the spectra of highly ionized atoms with greater accuracy than has hitherto been possible. The method has already been successfully applied to atoms in the first row of the periodic table and their isoelectronic sequences. Further developments, some of which will be carried through by students, are to include a study of the atoms in the iron group and their isoelectronic sequences; a systematic study of coronal lines, with an attempt to identify the remaining unidentified lines; and applications to the calculation of opacity in stellar interiors.

Miss Margaret Olmsted determined the photographic magnitudes (9.0 to 16.5) for sequences in three fields in Sagittarius-Scorpius, and the corresponding photored magnitudes (9.0 to 15.0) for two of these. Mrs. Jean H. Andersen began work on the colors of the Cepheid variables in one field. Identification charts for 47 variable stars discovered in past years at Harvard Observatory were requested by Dr. G. H. Herbig for Commissions 27 and 29 of the International Astronomical Union; Miss Arville D. Walker has confirmed the positions and variation of 38 of the stars on the list and Miss Olmsted has prepared identification charts for 20 of these for publication. Work on these projects will be continued during the coming year.

With support from the National Science Foundation, Dr. Sergei Gaposchkin spent the year at the Commonwealth Observatory, Mount Stromlo, Australia, engaged in a spectroscopic study of southern variable stars.

Dr. Albert G. Velghe continued as a Research Fellow until January. In the spring, three scientists were guest workers at the Observatory: Dr. Jean Bouchard, of the University of Dijon, was a Visiting Scholar under a Fulbright grant; Dr. Walter S. McAfee, of the U.S. Army Signal Engineering Laboratories in

New Jersey, was a Visiting Scholar in radio astronomy; Dr. Allan Sandage, Mount Wilson and Palomar Observatories, was a Visiting Lecturer.

Mr. Lawrence N. Mertz has constructed a polarization-type interferometer for use with the 24-inch reflector. Photoelectric stellar spectrophotometry is a somewhat insensitive technique when used with conventional scanning methods. By studying the Fourier transform of the spectrum rather than the spectrum itself (they contain the same information in different mathematical guise), we achieve a new and more powerful method of approach. The instrument constructed by Mr. Mertz greatly alleviates mechanical difficulties as well as problems of signal-to-noise ratio. The new interferometer, equivalent to a Michelson instrument, has produced preliminary measurements of the interference fringes of stars, and has demonstrated that various types of stars are readily distinguishable by this technique. Measurements of the Orion nebula and of Comet Arend-Roland clearly reveal their emission and band spectra, respectively.

Professor Thomas Gold studied the evidence for cosmic-ray effects of solar origin and their relation to the structure of magnetic fields in the solar system, and also worked on a new theory of magnetic storms. For the James Arthur Lecture at the Smithsonian Institution in Washington, he spoke on "Cosmic Rays from the Sun," and he has also lectured to a number of other scientific organizations.

Since his arrival here in February, Professor Gold has been actively concerned with the radio astronomy project, particularly with problems of future instrumentation. Dr. Harold I. Ewen continued to give counsel on the project. The National Science Foundation renewed its support of our research in radio astronomy.

Observations with the 60-foot George R. Agassiz radio telescope at the Agassiz Station started in July, 1956, under the supervision of Dr. T. K. Menon, Agassiz Radio Astronomer. With the new instrument, 21-centimeter studies of selected galactic regions reveal the amount and state of motion of neutral

hydrogen gas in certain stellar associations and in the vicinity of ionized hydrogen regions. Observations of extragalactic 21-centimeter radiation were made.

Dr. Menon continued his theoretical work on the Orion region, and his new observations show many interesting details of its expansion. He has also initiated a study of interstellar turbulence.

Mr. Campbell M. Wade completed his study of the expanding H-II region around Lambda Orionis, and used the results as material for his doctoral thesis.

Mrs. Nannielou Dieter worked at a survey of the galaxy Messier 33, which she finds to be associated with remarkably large amounts of hydrogen, extending far beyond the photographic limits of the object. She obtains a radio diameter almost three times the optical diameter. This result is of far-reaching import in theories of the origin and evolution of the universe.

The interstellar structure of the Cygnus region, the region around the expanding association I Lacertae, and the spiral structure of our galaxy from longitudes 170° to 200°, were studied by Mrs. May Kassim, Mr. William E. Howard, III, and Mr. Robert J. Davis, respectively. Miss Mary Connelley completed observations of the absorption spectra of the radio sources Cassiopeia A, Cygnus A, and Taurus A. A detailed study of the 21-centimeter continuum distribution around Cygnus X enabled Mr. Frank D. Drake to detect a number of discrete sources in its vicinity. He has started observations of the hydrogen content of various galactic clusters, in order to verify predictions from the theories of stellar evolution.

Since the radio astronomy project began in 1953, five doctoral theses based on work in the project have been submitted; and six graduate students are currently at work on theses in radio astronomy.

As a guest researcher at the Agassiz Station, Dr. David Heeschen, of Associated Universities, Inc., studied the neutral hydrogen distribution in a number of external galaxies and clusters of galaxies. He detected 21-centimeter radiation from M81, M51,

M32, the Hercules cluster of galaxies, and the Corona Borealis cluster of galaxies.

Dr. George Field, a Junior Fellow at Harvard, completed his search for possible intergalactic hydrogen by means of a study of the continuum intensities of Cygnus A and Cassiopeia A, and is now analyzing his observations. Dr. George Mumford, of Tufts College, used the 60-foot equipment for a study of the region around the Ophiuchus dark nebula.

Improvements of the electronic components of the 60-foot telescope, now in progress, will give the equipment higher sensitivity and stability without greatly increasing its complexity. During the coming year we plan to employ a full-time electronic engineer. An electronic technician, Mr. Gerald Abely, has been working at the Station since this spring.

The rehabilitation of the 61-inch reflecting telescope at the Agassiz Station is complete except for minor adjustments. The new right-ascension drive was delivered and installed during the year. A main control station for the telescope, built in the Observatory shop, houses the electronic parts of the drive, relays for the control circuits, clocks, indicators for the position of the telescope, and all control switches. The telescope can be set in right ascension and declination from this station. The observer has at his disposition a small panel at the focus, which duplicates the most essential dials and control switches.

The 61-inch was in temporary use for Dr. William Sinton's observations of Mars during its 1956 opposition. The image quality of some plates taken then at the Newtonian focus indicates that the new mirror support system is far superior to the one it has replaced. A modern high-dispersion spectrograph is urgently needed as an accessory for this instrument.

The 24-inch reflector was exclusively used for photoelectric photometry, mainly by Dr. G. R. Miczaika, Mr. Frank D. Drake, and Mr. Andrew T. Young with the infrared photometer, and by Mr. Lawrence N. Mertz with his photoelectric interferometer-type spectrograph. The two patrol cameras have been equipped

with new drives, built in the Observatory shop by Mr. Lionel Caron, machinist.

Professor Bruno Rossi, of the Massachusetts Institute of Technology, has installed a complex array of cosmic-ray counters at the Station, and has observed some of the most extensive showers of cosmic rays ever detected.

Improvements were made to the buildings and grounds at the Agassiz Station. The base of the 60-foot radio telescope was painted; the road and parking area were surfaced, and the necessary retaining wall and drainage have been constructed. Air conditioning was installed in the equipment room of the 60-foot laboratory building. The entire interior of the Central Building was painted, as well as the exterior trim and the interior of the Agassiz Cottage; new lighting fixtures and a sink were installed in the Cottage.

In August, 1956, Dr. Miczaika joined the Air Force Cambridge Research Center, Air Research and Development Command, and consequently was relieved of some of his responsibilities at the Observatory; he continues, however, as Astronomer-in-Charge of the George R. Agassiz Station.

Dr. Donald H. Menzel continued as project director of the two Air Force contracts that support solar research in Cambridge and the work at the Sacramento Peak Observatory, Sunspot, New Mexico, and the Radio Astronomy Station, Fort Davis, Texas. His own investigations have included studies of the nature of the solar corona and prominences and also of the ionosphere and solar activity. He is supervising a survey of all available data on cosmic radio noise, with the view of welding it into a consistent whole.

Dr. Richard N. Thomas made several trips to the Sacramento Peak Observatory and the High Altitude Observatory. In collaboration with members of the staff at Sacramento Peak, he analyzed chromospheric limb spectra obtained by them with the 16-inch coronagraph. With Dr. Jean-Claude Pecker, he investigated the problem of the source function in the upper photosphere

and lower chromosphere. Dr. Thomas completed work demonstrating the difference between electron and excitation temperatures for the early Balmer lines, and has applied it to the problem of analyzing these lines for atmospheric structure and abundance.

The structure of the sunspot zone, as shown in the distribution of sunspots with latitude over the solar cycle, was studied by Dr. Barbara Bell. She also continued her work on some statistics of sunspots and of flare production, discussing the frequency distribution of sunspot groups among the Mount Wilson magnetic classes; an east-west asymmetry in the distribution of sunspots on the solar disk, in the sense that more spots are seen to develop east than west of the central meridian; the relation of flare frequency to magnetic class and to the area of spot groups.

Mr. John G. Wolbach is analyzing various properties of solar flares, using Mount Wilson solar maps and High Altitude Observatory flare films with other data to construct magnetic and visual composite diagrams.

Dr. F. Shirley Jones, in collaboration with Dr. Menzel, continued the measurement and classification of solar prominences, working with data from Climax and Sacramento Peak. Analysis for the years 1949 through 1952 has been completed.

At Sacramento Peak Observatory the Harvard group made further improvements in instrumentation for the solar patrol activities. The 16-inch coronagraph on the 26-foot spar, with its accessory Littrow spectrograph, now makes routine observations. The patrol coronagraphs and accessory equipment were completely rebuilt. The patrol program includes direct and spectrographic daily records of the corona, flares, and prominences, and recording of sunspots.

Dr. Henry J. Smith, Astronomer-in-Charge of the Harvard program at Sacramento Peak, was principally concerned this year with the development and testing of instrumental accessories. Using the 16-inch coronagraph, the large Littrow spectrograph, and Dr. E. W. Dennison's direct-intensity microphotometer, Dr. Smith recorded and analyzed spectra of the low chromosphere.

He also extended the analysis of spectra of bright prominences observed with the patrol camera spectrograph.

Dr. Elske v. P. Smith completed an analysis of Hα spectra taken with the high-dispersion spectrograph of the 16-inch coronagraph, which gives information concerning the variation of the Hα profile with height in the chromosphere.

During the report year, Drs. John T. Jefferies, Max Krook, David Layzer, Alan Meltzer, Jean-Claude Pecker, and John H. Waddell, III, were also associated with the solar project, either in Cambridge or at Sacramento Peak.

At the new Radio Astronomy Station in Fort Davis, Texas, operated under contract with the U.S. Air Force, the 28-foot equatorially mounted paraboloid antenna was completed, and experimental observations began in August, 1956, with a temporary power supply. Automatic operation of the equipment, from sunrise to sunset seven days a week, started later in the fall after the installation of commercial power. Completion of the laboratory building, the power line, and a water system, and plans for auxiliary darkroom and office space in the town of Fort Davis, marked the progress of the physical plant.

The high sensitivity of the solar radio equipment — deriving from an antenna with increased collecting area and lower receiver noise figure — has revealed much new fine structure in the radio spectrum of noise storms, and also many other low-intensity phenomena not previously recognized. A new type of solar burst was detected on the records in the form of an inverted "U", apparently deriving from a disturbance moving outward through the solar atmosphere and then returning inward. All the radio observations are being correlated in time with optical observations of solar activity made at the Sacramento Peak Observatory. The station is now linked by radio with the Peak, the High Altitude Observatory, and the Climax station, and receives daily reports of solar activity.

Equipment at Fort Davis to supplement the dynamic spectrum analyzer and 28-foot dish includes an interferometer for rapid position measurements of solar disturbances, in the testing stage

by the summer of 1957. It consists of two primary antennas, separated by 1,000 meters on an east-west line, to accept simultaneous signals in the frequency range 110–140 megacycles per second. A sweep-frequency receiver is being planned to operate outside the 100–600 megacycle per second range of the existing equipment.

Dr. Alan Maxwell is Radio Astronomer-in-Charge at the Fort Davis station. His staff includes Messrs. Samuel J. Goldstein and Govind Swarup.

Professor Fred L. Whipple continued his activities as director of the Harvard meteor projects and Director of the Smithsonian Astrophysical Observatory. In September, 1956, he took part in the International Geophysical Year conference at Barcelona, and the International Federation of Astronautics Congress in Rome. Dr. Whipple was chairman of the Technical Panel on Rocketry and a member of the Technical Panel on the Earth Satellite Program of the International Geophysical Year; a member of the Panel on the Atmosphere, of the Scientific Advisory Board to the Air Force; a member of the committee on cosmic and terrestrial relationships of the American Geophysical Union. He continued to serve as editor of the Harvard Announcement Cards.

The meteor project, under the direction of Dr. Whipple and sponsored by an Air Force contract, continued to operate its observing station in Sunspot, New Mexico. The second station of the pair, formerly at Mayhill, was moved in April, 1957, to Organ Pass, New Mexico, to lengthen the baseline between the two stations. This reflects a change in emphasis of the program. Observations at present are directed toward the photography of persistent meteor trains which supply information on both the wind fields of the upper atmosphere and the structure of meteoroids. Photography of meteor trails continues at a reduced rate. Mr. Gunther Schwartz is Superintendent of the New Mexico stations.

As in the past, the optical facilities of the meteor project have been utilized to photograph special rocket flights from Hollo-

man Air Force Base in nearby Alamogordo, New Mexico. As part of a basic research program, the Air Force is "seeding" the upper atmosphere with known quantities of materials which interact with the atmospheric components, producing light. In the last year both ethylene gas and sodium vapor were released in an attempt to determine the concentration of atomic oxygen and atomic nitrogen in the atmosphere above 100 kilometers. Our super-Schmidt photographs yielded most of the information obtained from both flights. Dr. Richard E. McCrosky, Dr. Allan F. Cook, and Mr. Richard Rodman are co-operating with the scientists of the Air Force Geophysics Research Directorate in the analysis of these results.

Dr. McCrosky, under the sponsorship of a Navy contract, completed the reduction of 2,500 meteors and has determined distribution statistics for their orbital elements. This photographic study, showing the insignificant number of meteors originating from outside the solar system and the preponderance of meteors closely confined to the ecliptic plane, confirms results obtained by radar observations.

A search by Dr. McCrosky and Mrs. Annette Posen for new meteor streams has yielded six new showers including two associated with known comets.

Miss Frances W. Wright finished the analysis of the radiant motion and scatter for the Iota-Aquarid stream, and presented a paper on the "Photographic Iota-Aquarid Meteors and Evidence for the Northern Delta-Aquarids" at the New York meeting of the American Astronomical Society. She has begun a similar study for the Quadrantid meteors.

Dr. Luigi G. Jacchia supervised the work of reduction by accurate techniques of meteors photographed with the super-Schmidt cameras under an Army Ordnance contract. He carried out research on the physical nature of meteors by studying their deceleration and fragmentation inside the earth's atmosphere. He has found no clear-cut evidence for the presence of hard-bodied meteors of asteroidal origin among 361 super-Schmidt records analyzed. A comparison of visual and photographic magnitudes

showed that the "color index" of meteors is independent of velocity, but is strongly dependent on meteor brightness.

The radio meteor research program continued under the direction of Dr. Gerald S. Hawkins, supported by an Air Force contract. Visual meteor observations made in England between 1930 and 1949 were analyzed by Dr. Hawkins and Mr. J. P. M. Prentice, former director of the Meteor Section of the British Astronomical Association. Measurements of the width of meteor trails as recorded on the National Geographic Society-Palomar Observatory Sky Atlas were made by Drs. Hawkins, Payne-Gaposchkin, and Whipple. The terrestrial data, extracted by Dr. Hawkins and Mr. Richard B. Southworth from the 361 meteors in the short trail reduction program, will be valuable in extending the physical theory of meteors. A radiometer supplied by the Air Force Cambridge Research Center, through the co-operation of Dr. Jules Aarons, and the Observatory's 24-foot radio telescope at the George R. Agassiz Station have been used since January, 1957, to measure the fluctuation in intensity of the radio signals from Cassiopeia A.

The long-term agreement for the continued operation of the Boyden Observatory at Bloemfontein, South Africa, by an international co-operative group has been ratified by Harvard and Armagh, two of the six participating organizations. Although altered in minor details, the agreement stands essentially as outlined in this Report last year. At the meeting of the Boyden Administrative Council in Brussels on June 11–12, 1957, it was expected that the final agreement would be ratified soon by the other participants. Dr. Menzel continues as chairman of the Council.

The organization of the Association of Universities for Research in Astronomy, Inc. (AURA) has gone forward. Although this national optical installation will generally be open to astronomers of all observatories, a small group including the universities of Harvard, Ohio State, Indiana, Michigan, Chicago, Wisconsin,

and California (Berkeley) have joined to provide a management unit.

Following the advice of Mr. Edward Reynolds, Administrative Vice-President of Harvard University, the Observatory appointed a safety officer, Mr. John G. Wolbach, who prepared a thorough analysis of the safety situation both at the Cambridge observatory and at the Agassiz Station. "Occupational hazards" at both sites include the use of the telescopes, with normal attendant risks. These are being reduced as much as possible, and adequate instruction of people who use the instruments is mandatory. A number of Mr. Wolbach's recommendations were carried out this year; others will be followed as time and finances permit. Mr. Wolbach will continue to serve as Safety Officer, so that present and new problems relating to safety will remain under active consideration.

The renovation of Kittredge Hall at 79 Garden Street enabled the staff of *Sky and Telescope* to move there from the Observatory. Also, a number of people from the Smithsonian Astrophysical Observatory, chiefly those concerned with the satellite tracking program for the International Geophysical Year, now occupy space in Kittredge. This University building has solved some of our immediate housing problems, but acquisition of an additional building is an urgent consideration.

Adequate shop space is also a major need. Through a series of moves initiated this year, we have gained some additional space for the mechanical and electronic shop, but at the expense of other activities. A considerable number of tools and various pieces of machinery were acquired. Mr. Kenneth Covey joined the staff as a machinist. The shop is now jointly maintained by the Observatory and the Smithsonian Astrophysical Observatory.

Substantial improvements were made in the physical plant at Cambridge. The Building C parking lot and the parking area for Building D were paved. The buildings housing the 7½-inch and 9-inch telescopes, the shop and garage, were all painted on the outside. A Tozier Fund grant to the Department of Astronomy

enabled us to repair the dome and building of the 7½-inch instrument. The large basement room in Building C, painted and improved, was made available to the students as a lounge. Furniture in the tutorial library was renovated and two new chairs were bought.

This year also saw the completion of the second phase of our exhibit room plans — the conversion of the old prime vertical room into an extension of the George R. Agassiz Memorial Room. The cabinets and counter space for the various star charts are finished, and with the addition of the new display case for the Ernst sundial collection this "chart room" serves as an excellent complement to the other exhibits. An anonymous gift aided substantially in the work.

The announced goal for funds to take care of future needs of the Observatory is an increase in capital of $1,300,000. Our fund-raising plans are being closely correlated with the University drive. During this past year, gifts of $382,114 were received to increase already established endowments or to create new ones.

An anonymous gift increased the capital of the George R. Agassiz Station Fund by $350,000. The new Thomas C. Desmond Fund, through gifts from Mr. Desmond, a member of our Visiting Committee, amounts to $10,000. The new John G. Wolbach Fund, including gifts from Mr. Wolbach and an anonymous friend, now stands at $14,500. Mrs. Paul Barnet Gring, also a member of our Visiting Committee, contributed $1,000 to our Observatory Endowment account.

The Bart J. Bok Prize Fund was established this year by an anonymous gift, and was later increased to a total of $6,614 by contributions from 61 friends of Dr. Bok. The income will be used for a prize to be awarded, preferably biennially, to a recent recipient of a Ph.D. in the physical sciences from Harvard or Radcliffe, the award to be based preferably upon a doctoral thesis, book, or research paper, in the area of Milky Way research by observational methods.

All these gifts, and others for current use, are gratefully acknowledged. Among the other donors are Miss Martha Car-

michael, Mr. and Mrs. Marion Eppley, Mr. Paul Hammond, and the Bond Astronomical Club.

A filar micrometer was donated by Mr. Carl L. Bausch, of the Bausch and Lomb Optical Company.

This report places primary emphasis on scientific advances made during the year. The bibliography of Observatory reports and publications contains 136 items, in addition to 27 Announcement Cards, for the year 1956–57. The complete list of publications may be found in the Harvard College Observatory Director's Report (hectographed), 1956–57.

Donald H. Menzel
Director

HARVARD
ASTRONOMICAL OBSERVATORY

ANNUAL REPORT

1958

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Harvard College Observatory

To the Dean of the Faculty of Arts and Sciences:

Sir, — The Harvard College Observatory Council, consisting of Professors Cecilia Payne-Gaposchkin, Thomas Gold, Theodore E. Sterne, and Fred L. Whipple, Dr. Gerhard R. Miczaika, and myself, Professor Donald H. Menzel, take pleasure in submitting this annual report for the year 1957–58.

This year has been a significant one, as the point of view of all of us was dramatically changed on October 4, 1957, with the launching of the first Russian Sputnik. The space age will inevitably bring new and fresh approaches to our astronomical problems as we investigate ways and means of exploring farther out from the earth, and as instrumentation and observing techniques change and develop in this new world.

Our library at Harvard College Observatory, the Phillips Library, acquired 154 new items this year; the total number of volumes is now 9,764. During the year, 140 volumes were bound. A small library principally in the field of geophysics has been established by the Smithsonian Astrophysical Observatory. Carefully selected to avoid duplication with our own material, this library will add to the basic reference sources at the Observatory.

Professor Cecilia Payne-Gaposchkin continues as Chairman of the Department of Astronomy, with Dr. Frances W. Wright as Executive Secretary of the Department. Eighteen graduate students were in residence during the academic year. Campbell M. Wade, Jr., received a doctor's degree in March of 1958. In June, Mrs. Nannielou Dieter, Frank D. Drake, Mrs. May Kassim, and William E. Howard, III, received Ph.D. degrees, and Mrs. Mary-Jane Stewart Wade received an A.M. degree. Andrew T. Young was a National Science Foundation Fellow; three students held Agassiz Fellowships, Paul W. Hodge, Mr. Howard, and Carlos

M. Varsavsky; the last also received a scholarship from the Faculty of Arts and Sciences. Mr. Drake held an Elmer Scholarship; Richard G. Teske and Lawrence N. Mertz held Jewett Fellowships; and Mrs. Dieter received a Pickering Fellowship and a Radcliffe Fellowship. Most of the other graduate students were part-time teaching fellows or research assistants.

A series of seminars in astronomy brought six distinguished visitors for lectures during the year; the seminars were made possible through the support of the Higgins Trust. Dr. Henry J. Smith, Sacramento Peak Observatory, Dr. John D. Strong, Johns Hopkins University, Dr. Bengt Stroemgren, Institute for Advanced Studies, Professor W. A. Fowler, California Institute of Technology, Dr. Fred Hoyle, Cambridge University, England, and Dr. Martin Schwarzschild, Princeton University Observatory, participated in the series.

Professor Payne-Gaposchkin directed the Summer Conference for Teachers of Astronomy at the University of California.

Dr. Gerard de Vaucouleurs came to Harvard Observatory late in June as a Research Associate on a three-year appointment. He will continue his study of galaxies, begun at the Mount Stromlo Observatory in Australia and at the Lowell Observatory in Arizona. His principal research will be with Dr. Menzel, under contract with the U. S. Air Force, on problems of planetary atmospheres, particularly the physical and chemical characteristics of the planets. Mr. Hector C. Ingrao, senior research assistant on the project, has studied the feasibility of using an "evaporagraph" for infrared planetary photography. This imaging device, built and kindly loaned to the Observatory by Baird-Atomic, Inc., has been used with the 24-inch and 60-inch reflectors at the Agassiz Station.

Dr. David Layzer, with two graduate students, Mr. Fred A. Franklin and Mr. Carlos Varsavsky, has developed and applied a new method for predicting energy levels in transition problems of complex atomic spectra. The method can describe the structure of isoelectronic sequences, for which no previous theory was available. Recent calculations indicate that the method may prove

equally successful for predicting absolute transition probabilities, and thus contribute to the problem of determining the abundances of the chemical elements in stars. Dr. Layzer has developed a new theory for the formation of some of the elements, notably helium, in the initial stages of expansion of the universe. His theory requires fewer arbitrary assumptions and is simpler than previous concepts.

Dr. Max Krook has continued his research in fluid dynamics, kinetic theory, and stellar atmospheres. In particular, he has been investigating dynamical behavior in the outer layers of the sun and other stars.

Professor T. E. Sterne developed some new theories of general perturbations of the gravitational motion of satellites of oblate planets, applicable to artificial earth satellites. One theory was based on his discovery of a Hamiltonian function that was nearly correct but that led to an analytically soluble dynamical problem. The perturbations, to this novel and nearly correct unperturbed motion, are much smaller than the perturbations that affect the elliptical elements of conventional planetary theory.

He has also analyzed in detail the effects of aerodynamic drag upon satellite orbits, and has used the resulting methods to infer, from available orbital data, the density of the earth's atmosphere at great altitudes.

Professor Payne-Gaposchkin carried on her spectrophotometric study of the spectra of novae. She also continued the study of the light curves of Cepheid variables in the Small Magellanic Cloud, and their relation to the period-luminosity curve. She has been invited to speak on this subject at the meeting of the International Astronomical Union in Moscow in August, 1958.

Dr. Sergei Gaposchkin returned in September, 1957, from a year's stay at Mount Stromlo Observatory in Australia, where he obtained over 550 spectrograms of a number of southern variable stars. He intends to study the synchronous behavior of spectral lines, motions in the atmosphere, and brightness. Concurrently with the spectrograms, he obtained several hundred measures of the visual brightness of the three brightest Cepheids

and the brightest long-period variables. Noticeable progress was made in the study of the colors and magnitudes of two southern globular clusters, Omega Centauri and 47 Tucanae, to at least apparent magnitude 19.

Miss Margaret Olmsted completed the measurement of photographic and photo-red magnitudes of standard sequences in four absorption-study fields in the Sagittarius-Scorpius region; the photographic magnitudes are measured completely and the photo-red, nearly completely, for two fields in Carina. Miss Olmsted made a catalogue of data for all ADH plates at the Observatory, which is being mimeographed for distribution.

Dr. Walter McAfee, of the U. S. Army Signal Engineering Laboratories, continued at the Observatory until March, 1958, as a Visiting Scholar in radio astronomy.

Miss Frances W. Wright, appointed Lecturer in Astronomy for the second term, gave the course in Navigation, a field in which she is specially competent. She received a Ph.D. degree in astronomy from Radcliffe College in June, 1958.

Dr. Gerhard R. Miczaika continues his part-time duties as Research Associate and Astronomer-in-Charge of the George R. Agassiz Station. At the Station, the 24-inch reflector was used exclusively for photoelectric work, particularly by Mr. Lawrence N. Mertz with his interferometer-type spectrograph. Mr. Richard G. Teske has reconditioned the Newtonian spectrograph of the 61-inch telescope. The design of a new grating spectrograph for the Cassegrain focus of the 61-inch is nearly finished, and a gift has insured completion of this important equipment. Extensive work was done on the observing platform of the large telescope.

The 12-inch refractor and its housing have undergone considerable repair. An 8-inch Schmidt camera, built by Ridell Instruments, Inc., of Williams Bay, Wisconsin, was purchased and has been mounted on the 12-inch.

Professor T. Gold has worked on various phenomena connected with magnetic storms. With Professor Menzel, he presented at the radio noise conference in April a new theory to

account for certain rapid periodic fluctuations in the earth's field: that these are solar signals reaching the earth in cases of particular configurations of the magnetic field in the earth-sun space, a phenomenon called "solar whistlers." The theory of the cosmic-ray flare effect has been further elaborated, and was used to interpret the radiation effects discovered by Dr. J. Van Allen with the Explorer satellite. Professor Gold has lectured at various institutions, on cosmology and on branches of magnetohydrodynamics. He attended the Solvay Conference on Cosmology in Brussels in June, 1958.

Professor Gold has continued to direct operations with the 60-foot George R. Agassiz radio telescope. The National Science Foundation continues its support of this project. During the year, new receiver equipment was assembled by the Ewen Knight Corporation, and has been installed. Plans were completed for an extension to the laboratory building that will nearly double its capacity, and construction is under way with funds from an anonymous gift.

On January 1, 1958, Dr. Samuel J. Goldstein, Jr., became Radio Engineer at the 60-foot radio telescope; he had formerly been associated with the Harvard Radio Astronomy Station in Fort Davis, Texas.

Dr. T. K. Menon resigned his appointment as Lecturer and Agassiz Radio Astronomer, effective September 1, 1958, to go to the University of Pennsylvania. During this year, Dr. Menon has investigated the H-II region around the Orion nebula, and the structure of the Cygnus loop. His analysis indicates that the original explosion that was responsible for the structure must have taken place in an already dense cloud of neutral hydrogen.

Dr. Donald H. Menzel, under a contract with the U. S. Signal Corps, undertook an analysis of all existing data on cosmic radio noise, and used the data to prepare a series of radio noise maps in the form of a planisphere. Dr. Martha Hazen worked extensively on this project from September through April. With continued Signal Corps support, a conference on "The Radio Noise Spectrum" took place in Cambridge on April 22, 1958. About 250

persons attended as representatives of educational institutions, industry, and the military. Harvard staff members who presented papers were Dr. Menzel, Professor Gold, Dr. Gerald S. Hawkins, and Dr. Alan Maxwell.

The first award of the Bart J. Bok Prize was made to Dr. A. E. Lilley, of Yale University Observatory, at the conference. Dr. Lilley, who received his Ph.D. degree from Harvard in 1956, was honored for his radio astronomical researches concerning the structure of the Milky Way, and for his pioneering studies based on the 21-centimeter absorption technique.

Dr. Fred L. Whipple continued as Professor of Astronomy at Harvard and as Director of the Smithsonian Astrophysical Observatory. He was editor of the Harvard Announcement Cards, of the *Smithsonian Contributions to Astrophysics*, and of a new publication, *Planetary and Space Physics*. In June, 1958, he received an honorary Doctorate of Science from the American International College, Springfield, Massachusetts.

Dr. Whipple continued his research on meteors and has directed work for the contracts of the Harvard meteor project. He has studied various specific problems relating to observations of artificial earth satellites, and general problems of the exploration of space by manned and unmanned vehicles; he is preparing specific plans for an astronomical telescope in a satellite orbit.

The meteor project, under the direction of Dr. Whipple and Dr. Richard E. McCrosky, included optical observations of meteor trains and trails, and of special rocket flights which yield geophysical data. Two noteworthy trains photographed during the year are being analyzed by Dr. Allan F. Cook, for information on atmospheric winds and the structure and mass of the meteorites.

The super-Schmidt cameras have proved to be extraordinarily useful during the past year. In October, 1957, they provided accurate information on the orbit of the first Russian satellite. From December to May, two of them were lent by the Air Force to the satellite tracking program of the Smithsonian Astrophysical Observatory for use in Hawaii and Argentina. Dr. McCrosky and

Mr. Kenneth Morrison, on leave from Harvard, operated these stations.

Dr. Cook and Mr. Fred A. Franklin have surveyed the existing data pertaining to the rings of Saturn. They have determined limits on the transparency of the ring structure, and have predicted the gas pressure in the inner ring. Dr. Cook continues his co-operative research with the Dominion Observatory in the analysis of meteor spectra.

A contract with the Lincoln Laboratory of Massachusetts Institute of Technology supports basic research in the field of radio meteors. Dr. Gerald S. Hawkins and Mr. Edward K. L. Upton, from an analysis of super-Schmidt data, obtained an accurate estimate of the number of meteors that strike the earth each day. The influx rate was given as a function of the magnitude, mass, and electron line density of the meteor.

A search for radio noise from meteors, begun in 1955, has utilized magnetometers and radiometers operated in New Mexico and at the Agassiz Station in Harvard, Mass. No significant emission was detected in any of the experiments at the four frequencies chosen; it is probable that meteors are quiet over the entire radio spectrum.

The work of observers in the American Meteor Society was collated and published, under the radio meteor contract, by Dr. C. P. Olivier. This collection of visual data covering the past 50 years and many thousands of recorded meteors should be of value in future research.

A contract with the National Bureau of Standards has enabled the Observatory to begin an extensive experimental program for the study of meteors by radar. We are now constructing in Illinois a high-power radar network to operate at a frequency of 40 megacycles per second. This radio meteor project is under the direction of Dr. Whipple; the Astronomer-in-Charge is Dr. Hawkins, and the Project Engineer is Mr. E. Stuart Fergusson. We plan to measure the velocities and orbits of individual meteors that are at least 100 times fainter than those visible to the human eye. The data will yield information on the relation between

meteors, the zodiacal cloud, and comets, and on the interaction of meteors with the upper atmosphere.

Dr. Frances W. Wright has supervised the project of examining all meteor film taken with the super-Schmidt meteor cameras.

From a survey of 12 meteor showers photographed at Harvard, Dr. Wright has made a new observation concerning mean radiant paths of photographic meteor streams — that the sun is never more than a few degrees from the extended great circle through the mean daily path of radiant motion for the corresponding shower. When the earth takes some time in passing through the stream, the daily radiant seems to advance along a great-circle path toward the position of the sun at the time of maximum activity of the meteor shower.

Since October, 1957, Dr. Luigi G. Jacchia has worked principally on problems relating to artificial earth satellites. Before the satellite emergency began, he finished an analysis showing that the difference between the photographic magnitude and the estimated visual magnitude of meteors photographed with the super-Schmidts decreases from brighter to fainter meteors; the phenomenon is thought to be physiological in nature and is attributed to the Purkinje effect.

With the support of two Air Force contracts, Harvard College Observatory under the direction of Dr. Donald H. Menzel continues to carry on in Cambridge a program of research on solar phenomena, to operate the solar patrol instruments of the Sacramento Peak Observatory, and to collect and analyze solar radio data at the Radio Astronomy Station in Fort Davis, Texas. The results of this long-range program of solar research have led to major revisions in our understanding of the sun and its atmosphere. Dr. Menzel has presented the new concept in the completely revised edition of *Our Sun*, just sent to the Harvard University Press.

Dr. Barbara Bell spent several weeks at Sacramento Peak Observatory during the fall of 1957, where she made photoelectric tracings of a number of solar line profiles. From these, in collabo-

ration with Dr. Alan Meltzer, of Rensselaer Polytechnic Institute, she studied the relative half-widths of lines of different atomic weight, carbon, silicon, and iron, and found that the atomic weight dependence of the Doppler broadening of these lines corresponds to a kinetic temperature of about 10,000° K., a value substantially higher than that predicted by accepted theories of the solar atmosphere. The explanation remains unknown.

She completed a statistical study of sunspots and flare production, begun in collaboration with Mr. Harold Glazer. Mr. John G. Wolbach is working on the positions of individual flares in relation to sunspots.

Dr. Menzel, Mr. Lowell Doherty, and Dr. Martha Hazen have developed a general numerical method for analysis of the solar atmosphere. The method is now being tested on the prediction of curves of growth and line profiles.

Mr. Wolbach, in investigating the ionospheric F_2 layer, has studied the behavior of the critical frequency with respect to the sun's zenith angle, Zurich sunspot number, and geomagnetic index. The relation to spot number appears to vary with season, and the seasonal behavior of the ionosphere is unexpectedly different in the Northern and Southern Hemispheres. These studies emphasize the need for more extensive study of the ionosphere on a world-wide basis.

At Sacramento Peak Observatory, the Harvard solar project group participated actively in the International Geophysical Year program of solar patrol. The Harvard group has continued to record and report special types of solar activity to interested organizations. During July, August, and September, similar cooperation and a special teletype link between the Peak and San Nicholas Island, California, enabled the rocket research team of the Naval Research Laboratory to launch Nike-Deacon rockets at the onset of a solar flare, to permit high-altitude observations of solar Lyman-alpha radiation and soft X-rays.

The Littrow spectrograph for the 4-inch coronagraph was perfected. It features convenient interchange of three gratings, permitting low- and high-dispersion spectra (8 A/mm and 2

A/mm) between 3,600 and 12,000 angstroms of corona, prominences, and limb flares. The Harvard observers make preliminary analyses of coronal films for immediate radio transmission of data. Apart from the routine coronal patrol, the new coronagraph and spectrograph have proved very useful in the study of spectra of active regions at the limb.

Drs. Elske v. P. Smith and Henry J. Smith co-operated with Mr. John T. Jefferies, of the High Altitude Observatory, in recording panchromatic high-dispersion spectra of solar flares. This program was notably successful in recording a rich series of observations of the spectacular Importance 3 flare of September 18, 1957. The flare occurred near the center of the disk, and showed the Balmer lines, helium lines, and numerous neutral and ionized metal lines in emission.

After a one-month course on programming the Univac Scientific Computer at Holloman Missile Development Center, Dr. E. Smith and Dr. H. J. Smith, working with Dr. Jack B. Zirker, of Sacramento Peak, have undertaken a comprehensive program to reduce solar spectrographic observations automatically with the modern machine computers.

Mrs. Smith has secured high-resolution, high-dispersion spectrograms of the early Balmer lines in the chromosphere, and has completed a description of the profile of the H-alpha line.

Dr. Alan Maxwell remains in charge of operations at the Harvard Radio Astronomy Station in Fort Davis, Texas. The first full year of solar radio spectral observations was completed in September, 1957. At the end of 1957, a series of observations of active solar areas was made with a broad-band radio interferometer, set out on an east-west baseline one kilometer long.

A number of minor modifications have been made to the solar spectrum analyzer, including the provision of compressed response intermediate-frequency amplifiers, and circuits to switch on the r.f. tubes automatically after any power failure. Additions to the equipment at the station include a 60 Mc/s solar monitor receiver whose output is displayed on a pen recorder, and a crystal-controlled timing system.

The frequency range of the equipment, at present 100 to 580 megacycles per second, is being expanded. New receivers are on order to cover the range 25–50 and 50–100 Mc/s, together with equipment for extra recording channels, and a new camera system. A facsimile recorder will give a direct visual monitor of the output of one of the three receivers. A further survey of the radio interference in the area was made with field test equipment before we began work on the new low-frequency program.

The station now issues quarterly summaries of its spectral observations which are regularly distributed throughout the world.

Mr. Govind Swarup resigned in August, 1957, and Dr. A. R. Thompson joined the staff as Research Associate at that time.

The results obtained to date at the Radio Astronomy Station have exceeded expectations. The "U bursts," which occur when a blast of solar emission starts at high frequency, slowly changes to low, and then swings back to high, were first recognized at this observatory.

Dr. Menzel continues as chairman of the Boyden Administrative Council. The council meeting in Uccle, Belgium, in June, 1957, will be followed by one in Hamburg, Germany, in August of 1958. Experience this year has shown that the Boyden Observatory under the present arrangements can continue to be one of the world's valued and productive observatories. One of our Harvard graduate students, Mr. Paul Hodge, will spend about four months at Boyden in late 1958 and early 1959, for an extensive observing program.

Dr. Menzel and Mr. Edward Reynolds, Administrative Vice-President of Harvard University, continue to serve on the AURA (Association of Universities for Research in Astronomy, Inc.) Board of Directors, made up of a scientific and an administrative representative from each of the participating universities. With National Science Foundation support, AURA will conduct basic research in the field of astronomy and will construct, operate, and maintain the National Astronomical Observatory. The site for the new observatory is Kitt Peak, 40 miles southwest of

Tucson, Arizona, at an altitude of 6,895 feet. Work on the national installation is under way, with equipment to include initially a 36-inch and an 80-inch telescope. Harvard's access to this mountaintop observatory in the deep Southwest should enable us to broaden our observational attack on stellar problems, and should be an invaluable adjunct to our training program for graduate students.

Our need for additional space remains acute because of activities in the Observatory itself, contracts that are of direct interest to us, and the Smithsonian needs. The situation was improved temporarily when we were able to assist the Smithsonian in renting a Radcliffe College building at 51 Garden Street.

Mr. John G. Wolbach continues as Observatory Safety Officer, with responsibility for assuring conditions of maximum possible safety in operational and scientific activities both in Cambridge and at Agassiz.

Gifts and additions to funds are gratefully acknowledged from Mr. Alan C. Bemis, Mr. Thomas C. Desmond, the Constance R. Eppley Foundation, Dr. Marion Eppley, Mrs. Helen B. Gring, Mrs. Paul Hammond, the Higgins Trust, the James Craig Joyner Foundation, Mr. William S. Lindsley, Alfred L. Loomis, Jr., and Henry Loomis, the Loomis Foundation, Dr. C. E. K. Mees, Mrs. Walter H. Page, Mr. John G. Wolbach, and several anonymous donors.

A bibliography of Observatory reports and publications may be found in the Harvard College Observatory Director's Report (hectographed) for 1957–58.

Donald H. Menzel
Director

HARVARD
ASTRONOMICAL OBSERVATORY

ANNUAL REPORT

1959

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(*Preprinted from the Report of the President of Harvard College and Reports of Departments, 1958–59*)

Harvard College Observatory

To the Dean of the Faculty of Arts and Sciences:

Sir, — The Harvard College Observatory Council, consisting of Professors Cecilia Payne-Gaposchkin, Thomas Gold, Theodore E. Sterne, and Fred L. Whipple, Dr. Gerhard R. Miczaika, and myself, Professor Donald H. Menzel, take pleasure in submitting this annual report for the year 1958–59.

Plans for a new building on Observatory Hill are nearing completion. Harvard University will finance construction of the 40,000-square-foot building, most of which will be leased to the Smithsonian Astrophysical Observatory now occupying space in existing Observatory buildings and other locations in Cambridge. Both the Harvard and the Smithsonian Observatories will use the high-speed computing facilities, the laboratories, shop areas, and library. The structure, with a full basement and three floors, will be located east of the present complex of buildings.

The resignations of Dr. Gold as Professor of Astronomy, and of Dr. Sterne as Simon Newcomb Professor of Astrophysics, took effect at the close of this academic year. Dr. Gold will go to Cornell University and Dr. Sterne to Johns Hopkins University. Dr. Henry J. Smith resigned in April, 1959, as Astronomer-in-Charge of the Harvard observing program at Sacramento Peak to accept appointment with the Sacramento Peak Observatory. Miss Margaret Olmsted retired in December, 1958, after long association with Harvard College Observatory.

Dr. Max Krook received the appointment of Professor of Applied Mathematics and Astrophysics, in July, 1959. Dr. A. Edward Lilley joined the Harvard Faculty in July, 1959, as Visiting Lecturer.

Fourteen astronomers from Cambridge and two from our staff at Sacramento Peak attended the Tenth Congress of the Inter-

national Astronomical Union in Moscow in August, 1958. Many of them participated in other scientific conferences in Europe during that summer.

Professor Payne-Gaposchkin continued as Chairman of the Department of Astronomy, with Dr. Frances W. Wright as Executive Secretary. Sixteen graduate students were in residence during the academic year. Carlos M. Varsavsky received a Ph.D. degree in March, 1959, and Eugene E. Epstein, an A.M. degree in June.

During the fall term Dr. Walter Baade, formerly of Mount Wilson and Palomar Observatories, gave the lectures in Galactic Structure, Astronomy 211.

Mr. Paul W. Hodge spent six months at the Boyden Observatory in Bloemfontein, South Africa, obtaining plates for photometry of stars in the Large Magellanic Cloud. Mr. Fred A. Franklin is spending seven months at Boyden to study the size distribution of particles in Saturn's rings from photographic and photoelectric observations.

Professor Payne-Gaposchkin has continued her work on variable stars, particularly the spectra of novae. She contributed the article on the Galactic Novae to Volume 51 of the *Handbuch der Physik* (Springer, 1958). She delivered the 28th Joseph Henry Lecture at the Philosophical Society of Washington in May, 1959.

Dr. Sergei Gaposchkin has investigated about 185 of the 573 spectrographic plates he took in Australia. He analyzed the changes in velocity and in the different layers for the Cepheids Kappa Pavonis ($P = 9^d.1$), Beta Doradus ($P = 9^d.8$), and L_2 Carinae ($P = 35^d.5$). The brilliant Wolf-Rayet star, Gamma Velorum, has been shown to be an eclipsing variable with two components visible, one in absorption and the other in emission ($P = 16^d.2$, $m = 1.7$, uneclipsed). It is one of the heaviest stars in the sky. Dr. Gaposchkin continues his study of blue and red plates for magnitudes, colors, and population distribution in the two brightest globular clusters, Omega Centauri and 47 Tucanae.

Professor Gold carried out theoretical investigations of the Van Allen radiation zone, and of the general question of particle fluxes and magnetic fields in the solar system. His studies of the dynamics of the earth's outer atmosphere and the nature of the magnetic restraints may relate closely to problems of ionospheric motions and other high-altitude phenomena, including the so-called "Argus" effect.

In collaboration with M. Harwitt, an M. I. T. graduate student, Dr. Gold carried out experiments relating to erosion of the lunar surface, and demonstrated the importance of electrostatic forces on dust particles in the presence of bombarding electrons. Migrations of surface dust on the moon may be attributed to such an effect.

Dr. Krook developed a number of mathematical procedures for solving the structure equations for non-gray stellar atmospheres. Calculations with one of these methods, made by John Gaustad and Peter Stone, show that the method converges rapidly. Dr. Krook also continued investigations in the kinetic theory of neutral and ionized gases. He has developed and applied new types of approximation procedures to solve the kinetic equations for the structure of shock fronts, and for other nonlinear problems.

Dr. David Layzer continued his study of the theory of atomic spectra, and developed a screening theory of atomic spectra. Mr. Daniel Thompson, Dr. Varsavsky, Dr. Ali Naqvi, and Mr. Franklin assisted Dr. Layzer in this work, which has been partially supported by the National Science Foundation.

Dr. Menzel directed research on planetary atmospheres, under contract with the U. S. Air Force. With Dr. Gerard de Vaucouleurs and Mr. Hector C. Ingrao, he investigated the technical problems of high-resolution photography and spectroscopy of the planets by means of telescopic systems in both manned and unmanned balloons.

Following intensive planning through the spring months, expeditions to make visual, photographic, and photoelectric observations of the occultation of Regulus by Venus on July 7, 1959,

were sent to seven observatories in Spain, France, Italy, and Lebanon; and equipment was supplied to the Boyden Observatory. Observations of this very rare phenomenon may determine the scale height in the upper atmosphere of Venus. The U. S. Air Force and the Boeing Airplane Company provided support for the expeditions, and the Smithsonian Astrophysical Observatory cooperated in the observations.

Dr. de Vaucouleurs has begun the photographic mapping of surface and atmospheric features of Mars, using photographs kindly made available by Dr. W. S. Finsen, Union Observatory, Johannesburg, South Africa, and by Dr. R. B. Leighton, from the Mount Wilson Observatory.

Dr. de Vaucouleurs has analyzed visual and photoelectric observations of Mars made by him at the Lowell Observatory in October and November of 1958. He measured the Russell-Bond albedo of the planet at five wavelengths from $\lambda 3300$ to $\lambda 6900$. In the near ultraviolet ($3000 < \lambda < 4000$) Mars appears "gray" and very dark (albedo = 0.046), a result difficult to reconcile with some current ideas on the nature of the blue haze. Observations of an outstanding yellow cloud (October 13–22, 1958) yielded significant new information on atmospheric circulation and diffusion rate.

Dr. de Vaucouleurs, in collaboration with Mrs. Antoinette de Vaucouleurs, continued the reduction of photographic, spectroscopic, and photoelectric observations of bright galaxies that had been secured in previous years. Observations from the Mount Stromlo Observatory yielded material for a classification and radial velocity survey of 50 southern galaxies, and a new determination of the rotation curve and mass of the Large Magellanic Cloud from optical radial velocities of emission nebulosities. A photoelectric survey of magnitudes and colors of 124 northern galaxies, and a detailed determination of the color and luminosity distributions in Messier 33, were made from observations obtained at Lowell Observatory.

With support from the National Science Foundation, Dr. de Vaucouleurs initiated a two-year program of photographic pho-

tometry of bright galaxies, using mainly Mount Stromlo plates, to study the luminosity distribution laws in relation to galaxy types, and to determine integrated photographic magnitudes of southern galaxies.

Dr. Whipple continued as Professor of Astronomy at Harvard and as Director of the Smithsonian Astrophysical Observatory. He was elected to the National Academy of Sciences in April, 1959. He completed a study of the distribution of semi-major axes among comet orbits, which applies stochastic methods to determine the distribution of potential lifetimes among comets newly introduced to the inner regions of the solar system. For the long-period comets, the lifetimes follow a distribution law according to the inverse $1.5–1.7^{7}$ of the lifetime. Random perturbations by Jupiter can account for the long-period comets, but close approaches of this planet are probably required to account for the occurrence and distribution of the short-period comets.

Dr. Whipple and Robert J. Davis completed the design of a telescope for use on a satellite in space. Fitted into a socket in a "stable platform" within a satellite, the telescope will obtain important astrophysical data. The chief goals at present include an ultraviolet survey of the sky in three wavelength regions, and spectroscopic studies of particular celestial objects. Completion of the project will require about three years.

The meteor project, under the general direction of Dr. Whipple and the detailed direction of Dr. Richard E. McCrosky, received continuing support from the Air Force. Routine operation of the stations at Sunspot and Organ Pass, New Mexico, stopped indefinitely on January 15, 1959. In the previous seven years some 6,600 double-station meteors were photographed. Future operation of the stations will depend on the development of new observing techniques.

Dr. Allan F. Cook continues his analysis of meteor trains for the determination of upper atmospheric winds and the structure

and mass of meteors. The work of Dr. Cook and Mr. Franklin on the structure of Saturn's rings is progressing.

Dr. McCrosky analyzed the available data from an Air Force attempt to produce artificial meteors by the high-velocity ejection of material from rockets. The technique may prove useful in calibrating the mass scale of natural meteors.

Dr. Wright analyzed the radiant motion and scatter for the photographic Lyrid meteors. She continued to supervise the examination of all meteor film taken with the Baker super-Schmidt cameras.

The research program supported by the Lincoln Laboratory of M. I. T. continued. In the field of meteor astronomy, Dr. Gerald S. Hawkins and his group have found that the vestigial remains of the great Andromedid meteor swarm are now scattered over a wide area in the plane of the original comet orbit. A table of orbital elements of 360 meteors photographed by the super-Schmidt cameras has been compiled. Dr. Hawkins has shown that the dividing line between cometary meteors and asteroidal particles occurs at a visual magnitude of −3. Fireballs brighter than that magnitude are largely produced by solid fragments from broken asteroids; meteors fainter than −3 are largely produced by the low-density "dust balls" that are produced by comets. In the field of meteor physics, Drs. Cook and Hawkins have shown that the radar echo from the head of a meteor probably results from photo-ionization of oxygen molecules, and Dr. W. E. Howard and Dr. Hawkins made a photometric study of the decay of light from enduring meteor trains. Mr. Donald M. Lazarus completed a theoretical investigation of the ionization cross-section for the collision of sodium atoms on an atmosphere of oxygen atoms; this work relates directly to the ionization process in meteor trails.

The Harvard radio meteor project, under Dr. Whipple's direction, received continued support from the National Bureau of Standards. The construction and testing of electronic equipment began in 1958. At the new Long Branch Field Station in Havana, Illinois, meteors will be tracked by means of radar reflections to

obtain data on the velocity, radiant, and orbit of individual meteors. A large "trough" antenna was constructed by Radiation Engineering Laboratory at the main site and the transmitter has already been put into operation by the National Bureau of Standards. Microwave radio relay links have been installed by Raytheon and the constructional work at the site is almost completed.

At the George R. Agassiz Station, Dr. Gerhard R. Miczaika continues as Astronomer-in-Charge. The 24-inch reflector was used for photoelectric work by Dr. Cook and Mr. Young, and a commercial amplifier for the photometer was purchased.

The optics of the 61-inch telescope were realuminized in the summer of 1958. The ultraviolet spectrograph was reconditioned, and is now being used at the Newtonian focus. A grating spectrograph for the 61-inch has been ordered from Boller and Chivens, South Pasadena, California, for completion in 1960.

The radio astronomy group continued work at the Station, under Dr. Gold's direction. The new 21-cm receiving system was brought to a reliable working condition. The preamplifier is now mounted in a box in the focus of the 60-foot antenna. A very considerable improvement of stability and sensitivity has been obtained. Observations were mostly to test the new system. Mr. Robert J. Davis completed his surveys of a galactic region. Broad-band noise from Jupiter has been under observation, following the announcement from Green Bank that anomalous centimeter radiation comes from Jupiter.

A 21-cm Maser system, constructed by Dr. John V. Jelley and Mr. Brian F. C. Cooper in Gordon McKay Laboratory with the help of Dr. N. Bloembergen and other members of the Applied Physics Department, has worked very satisfactorily and is small and light enough to be attached at the focus of the 60-foot dish. Installation is scheduled for late summer of 1959. A platform has been built for work with the Maser on the 60-foot dish. A receiving system for the hydrogen-line Zeeman effect is also under construction.

Dr. Menzel directed the activities of the Harvard groups working on solar research in Cambridge, at the Sacramento Peak Observatory in Sunspot, New Mexico, and at the Radio Astronomy Station in Fort Davis, Texas, with continued support from the Air Force Cambridge Research Center. He further developed his studies of the form and structure of solar prominences, especially as they relate to the solar corona. Recent $\lambda 5303$ coronal photographs from Sacramento Peak are of high quality and show structural details not previously observed.

Motion picture records indicate that, in many instances, prominences at low temperatures and high densities condense from the corona at high temperatures and low densities. In Cambridge, Dr. Martha Hazen and Mr. Lowell Doherty have collaborated with Dr. Menzel in investigating the relative importance of various processes responsible for the cooling of the corona. The ultraviolet radiation field in prominences determines the relative numbers of neutral and ionized hydrogen and helium atoms which produce the visible light of the prominence. They found also that radiation from the million-degree corona contributes little directly toward establishing the hydrogen and helium abundances, but the heavier elements on which the corona can act more effectively in turn strongly affect the light ions.

Dr. Barbara Bell used Mount Wilson data on the magnetic field strengths and numbers of sunspots for the years 1917–1958 to study the structure of the sunspot zone as a function of heliographic latitude. She found some, but inconclusive, evidence in favor of the hypothesis that several zones of activity develop in each solar hemisphere, and that the zones remain stationary in latitude and are just sufficiently out of phase to simulate the latitude shift over the solar cycle described by Spoerer's law.

Mr. John G. Wolbach continued his study of the F_2 layer of the ionosphere. From characteristics of about 75 stations he found evidence for six categories of f_0f_2 variation with time. The characteristics of low-latitude stations in the northern hemisphere are found in certain southern hemisphere stations even at high latitudes, particularly at sunspot minimum. At sunspot

maximum these stations tend more to show the expected variation with southern season.

The period of this report covers the last six months of the International Geophysical Year (IGY), and the first six months of its extension. The Harvard solar project at Sacramento Peak, in addition to its patrol function, supplies descriptions and copies of routine and special observations of outstanding events to many astronomers throughout the world.

The 4-inch patrol coronal spectrograph has been employed, under the direction of Dr. F. Q. Orrall, of the Sacramento Peak Observatory, for the study of highly energetic, transient phenomena in the chromosphere and corona. Unique and valuable spectroscopic data in the near ultraviolet were obtained from loop prominences, surges and eruptive prominences, and limb flares.

The 6-inch coronagraph produced excellent cinematographic observations of the Fe XIV emission line corona; no other observatory is making these observations of coronal forms and behavior. A polarizing beam splitter added to the 6–inch coronagraph permits simultaneous observations of prominences in $H\alpha$ and at a slightly displaced wavelength, yielding line-of-sight velocities for study of prominence motions in three dimensions.

At the large dome, housing the 16-inch coronagraph and accessories, the large-scale disk cinematograph and Universal spectrograph have been remounted to provide greater speed and facility of operation.

In the area of specialized research at Sacramento Peak, Dr. Elske v. P. Smith made further observations of the height gradient of chromospheric hydrogen line profiles. In collaboration with J. T. Jefferies and J. Zirker, she has secured observations of sensitive metallic lines in the spectrum of chromospheric plages. A study of infrared neutral oxygen lines in solar flares, begun in the spring of 1959, is of particular interest in connection with satellite observations of the ultraviolet spectra of flares.

Dr. Henry J. Smith completed a study of the heliographic distribution of solar flares and, with Dr. E. Smith, continued to collect Universal spectrograms of bright prominences and limb

flares, and high-resolution Hα cinematograms of chromospheric activity.

Drs. H. and E. Smith have designed and tested a number of automatic digital computer programs for the reduction of spectrophotometric data, using the Univac installation at the Holloman Air Force Base. This work involves techniques to interpret the specialized format of microdensitometer data and to smooth photographic grain noise, and tests of all well-known methods for correcting spectroscopic observations for instrumental profile.

The 0.5A flare-patrol camera made high-rate cinematographic studies of the Hα activity of the chromosphere, as well as routine surveys. Results from the Fort Davis dynamic spectrum analyzer have shown that the normal 5-minute or 2.5-minute rate of the flare patrol fails to reveal a major part of the time spectrum of solar activity. The few high-speed sequences obtained to date do not show complete correlation between activity in the radio spectrum and Hα, but a new category of short-lived events, "high speed brights," has been detected.

Dr. Alan Maxwell remained in charge of the Radio Astronomy Station at Fort Davis, Texas. The sweep-frequency equipment there now includes a further two octaves of the electromagnetic spectrum. The two new receivers, 25–50 and 50–100 Mc/s, began operating in January, 1959. The Station has acquired a fluxgate magnetometer, to record the transient variations in the terrestrial magnetic field. Units were built to calibrate the solar spectral equipment automatically in frequency and intensity. Additional sweep-frequency equipment, to cover the range 2000–4000 Mc/s, is under construction.

A statistical analysis of the solar radio emissions at four frequencies, 125, 200, 425, and 550 Mc/s, was completed at Fort Davis for the Rome Air Development Center. The analysis included a detailed examination of the frequency-time profiles of the solar bursts interpreted in terms of their spectral characteristics.

An extended program on the correlation of radio bursts with the occurrence of optical disk phenomena has been completed. The analysis covered a two-year period at sunspot maximum and compared some 10,000 radio bursts with 2,000 solar flares. Further theoretical work included a comparison of the slow-drift radio bursts with the occurrence of terrestrial magnetic storms and aurorae, and a study of the correlation between solar bursts and cosmic rays. Most of the latter work was carried out with the IBM 650 computer at the National Bureau of Standards in Boulder.

We are happy to acknowledge gifts and fund additions from the Boeing Airplane Company, Mr. Thomas C. Desmond, the Constance R. Eppley Foundation, Dr. Marion Eppley, Mr. and Mrs. Philip S. Fogg, the Higgins Trust, the James Craig Joyner Foundation, Mr. William S. Lindsley, Mrs. Walter H. Page, Mr. John G. Wolbach, and an anonymous donor.

A bibliography of Observatory reports and publications issued during the year 1958–59 is available on request from the Librarian, Harvard College Observatory, Cambridge 38, Massachusetts.

Donald H. Menzel
Director

HARVARD
ASTRONOMICAL OBSERVATORY

ANNUAL REPORT

1960

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Harvard College Observatory

To the Dean of the Faculty of Arts and Sciences:

Sir, — The Harvard College Observatory Council, consisting of Professors Max Krook, David Layzer, A. Edward Lilley, Cecilia Payne-Gaposchkin, Fred L. Whipple, and myself, take pleasure in submitting this report for the year 1959–1960.

Dr. Lilley became Associate Professor of Astronomy in January, 1960. Other permanent appointments to be effective in July of 1960 were announced this spring: Dr. Leo Goldberg, University of Michigan, becomes Higgins Professor of Astronomy; Dr. Layzer, Professor of Astronomy; and Dr. William Liller, also from the University of Michigan, Professor of Astronomy. Dr. Gerhard R. Miczaika resigned at the close of 1959.

Construction of the new building B on Observatory Hill proceeded rapidly through the winter and spring. Occupancy is expected in early 1961.

Professor Payne-Gaposchkin served again as Chairman of the Department of Astronomy, until June 30, 1960, when Professor Liller becomes the new Chairman. Dr. Frances W. Wright continued as Executive Secretary. Twenty-one graduate students were in residence during the academic year. Paul W. Hodge and Robert J. Davis received Ph.D. degrees in March, 1960, and Richard B. Southworth received an A.M. degree.

Professor Menzel conducted a Freshman Seminar under the new Harvard Program of Advanced Standing. Twelve selected students participated in this teaching innovation, the primary aim of which is to establish a close relationship between outstanding students and a professor at an earlier stage than has been allowed by the usual curriculum. Under Dr. Menzel's guidance, these students carried out scientific research individually and collec-

tively, beginning with observation from an airplane of the total solar eclipse of October 2, 1959.

Dr. P. L. Bhatnagar, of the Indian Institute of Science in Bangalore, was Visiting Professor at the Observatory for the 1960 spring term. He conducted the course on Stellar Interiors. His visit was sponsored through a grant from the National Science Foundation to the American Astronomical Society, for support of a program of Foreign Visiting Professors in Astronomy. The grant was designed as a contribution to graduate astronomy instruction in the United States; Harvard became a pioneer participant through this appointment.

Dr. Layzer received the second award of the Bart J. Bok Prize on May 12, 1960, for his recent research paper, *On a Screening Theory of Atomic Spectra.* The study has yielded simple quantitative predictions of the structure of the spectra of complex atoms, in close agreement with experiment.

Professor Payne-Gaposchkin continued her research on the color, brightness, and form of the light curve of Cepheids. She studied R Coronae Borealis and RV Tauri stars, and is working on two manuscripts: *Variables and Evolution of the Galaxy*, and *Novae-Supernovae and the Birth of Stars.*

Dr. Sergei Gaposchkin completed measurements of his spectra of the Cepheids β Doradus, κ Pavonis, and L_2 Carinae, and the Wolf-Rayet stars γ Velorum and ζ Puppis, and two eclipsing binaries. He continued work on the colors, magnitudes, and two-dimensional distribution of the stars in the globular clusters ω Centauri and 47 Tucanae.

Dr. Gerald S. Hawkins reopened a discussion of the static solutions in cosmology. Einstein assumed the universe to be a uniform fluid with positive pressure; de Sitter assumed the pressure to be zero. Hawkins showed that if a negative pressure is assumed, equal in relativistic units to the mean density, then a third static solution is possible. Although this solution is mathematically valid, only further observational work can determine whether it describes the actual universe of galaxies. The critical

parameter to determine is the mean density of the universe. This third solution predicts a redshift that is directly related to the mean density and increases quadratically with distance.

Professor Krook continued his studies in the kinetic theory of neutral and ionized gases and in the theory of stellar atmospheres.

Professor Layzer further developed his screening theory of complex spectra, and, in association with John Bahcall, extended the theory to take into account relativistic effects. With Dr. Carlos Varsavsky, he continued work on application of this theory to the problems of electric-dipole transition probabilities.

To avoid certain earlier difficulties with boundary conditions, Dr. Layzer formulated the fundamental equations of his microscopic theory of ionospheric cross-modulation as integral equations. He developed an improved criterion for the onset of turbulence resulting from shear flow in a stably stratified atmosphere. This criterion forms the basis of a new theory of discrete reflecting layers (in particular, sporadic-E) in the earth's upper atmosphere.

With sponsorship of the National Aeronautics and Space Administration, Dr. Lilley and Professor Dirk Brouwer of Yale University co-direct a project to measure the distance from the earth to the sun by radio astronomical techniques. The accurate measurement of this distance is particularly important to space scientists who need the scale of the solar system in miles for the navigation of space probes.

Under Dr. Lilley's direction, and with Air Force support, radio telescopes have been designed and constructed for transportation in rocket probes and satellites. A number of these radio telescopes are in various stages of preparation for actual use in the Midas and Samos satellite programs.

Dr. Menzel directed research on planetary atmospheres, under contract with the U.S. Air Force. He collaborated with Dr. Gerard de Vaucouleurs and Hector C. Ingrao to investigate the technical problems of high-resolution photography and spectroscopy of the planets by means of telescopic systems in both manned and unmanned balloons.

Dr. G. and Mrs. A. de Vaucouleurs analyzed the astrometric data of the occultation of Regulus by Venus from the visual and cinematographic observations obtained by the Harvard expeditions, from published data from other stations, and from photoelectric observations of ingress at Le Houga and Bloemfontein.

To meet the need for an accurate standard map of Mars, Dr. de Vaucouleurs and his group have produced a detailed compilation of basic areographic co-ordinates of surface details using all available visual and photographic observations from 1909 to 1954. These observations were recorded on punch cards and will be used for the derivation of improved areographic co-ordinates of several hundred well-defined points on the Martian surface.

Measurements of the areographic co-ordinates of over 500 points were also obtained from the visual observations made by Dr. de Vaucouleurs at the Lowell Observatory during the 1958 opposition of Mars. The data, recorded on punch cards, were reduced by the computing section of the Jet Propulsion Laboratory, Pasadena, by courtesy of Dr. A. R. Hibbs.

Over 6,000 photographs of Mars, secured by Dr. R. B. Leighton in 1956 with the Mount Wilson 60-inch reflector, were used to prepare 740 enlarged composite prints on film. Accurate areographic co-ordinates of surface and atmospheric details will be measured on these photographs.

Under the sponsorship of the Air Force, and later of NASA, Dr. Menzel and Mr. Ingrao are studying infrared instrumentation in order to make heat maps of the moon and planets by thermal photography. Some preliminary results have been obtained by evaporograph and condensograph techniques.

Dr. de Vaucouleurs, supported by grants from the National Science Foundation, continued his studies of bright galaxies. Isophotes and photometric profiles of about 50 galaxies south of declination $-35°$ were derived from photographs taken by Dr. de Vaucouleurs at Mt. Stromlo Observatory. He published a new determination of the rotation and mass of the Large Magellanic Cloud from optical radial velocities of emission nebulosities

observed in 1956 at Mount Stromlo, and a reduction to the standard B, V system of all previously published data on the luminosity and colors of the Magellanic Clouds.

From an analysis of radial velocities, Dr. de Vaucouleurs concluded that the nearby Sculptor group has positive total energy and may constitute an expanding association of the type predicted by Ambartsumian. Dr. de Vaucouleurs continued work on the revision of the Shapley-Ames Catalogue. This revised and up-to-date *Reference Catalogue of Bright Galaxies* should be ready for publication in 1961 and will probably appear as a volume of the Harvard Annals.

A grant from the American Philosophical Society permitted Dr. de Vaucouleurs to continue star counts on plates of M33; this study will give new information on the luminosity function of supergiant stars.

Dr. Whipple continued as Professor of Astronomy at Harvard and as Director of the Smithsonian Astrophysical Observatory. Besides supervising the various meteor projects, he extended his research on the nature of cometary nuclei.

Drs. Luigi G. Jacchia and Whipple completed their analysis of 414 accurate photographic meteor orbits. These results, demonstrating the cometary origin of practically all photographic meteors, also indicate that the lifetimes of meteoroids in space are quite limited, at most of the order of 1,000 or so revolutions.

Dr. Hawkins found that there is a smooth distribution in numbers and sizes of asteroids, fireballs, and meteorites. The mass distribution is the same as that produced in rock-crushing processes under conditions of "overgrinding." He concluded that asteroids and meteorites have undergone many collisions in space. The influx rate of meteorites is the equivalent of one object weighing 4,000 tons or more striking the earth per century.

The meteor project, under the general direction of Dr. Whipple and the detailed direction of Dr. Richard E. McCrosky, received continuing support from the Air Force. Dr. McCrosky, in co-operation with the Pilot Chemical Company of Water-

town, Mass., is studying the development of a plastic prism for routine photography of the spectra of faint meteors. With Mrs. A. Posen, he completed an analysis of the orbits of meteors photographed in 1952–1955.

In his program on the analysis of meteor trains to determine upper atmospheric winds, Dr. Allan F. Cook studied the propagation of gravitational waves upward from the tropopause as a possible explanation for the observed winds (a mechanism suggested by C. O. Hines of the Defense Research Board of Canada). With Dr. Peter M. Millman of the National Research Council, Dr. Cook finished his study of the spectrum of a very slow meteor photographed in 1952 from two Canadian stations.

Fred A. Franklin is reducing the observations of Saturn and its rings, which he obtained during the 1959 opposition at the Boyden and the Lamont-Hussey Observatories at Bloemfontein. He and Dr. Cook have nearly finished an analysis of the structure of the rings.

Drs. Cook and Hawkins completed an analysis of the moving radar head echo associated with two bright meteors, and validated the suggestion of Drs. McKinley and Millman that these echoes are caused by photoionization of the air by meteoric radiations.

Dr. Frances W. Wright prepared for publication a detailed account of her observation, based on a survey of twelve showers photographed at Harvard, concerning the mean radiant paths of photographic meteor showers.

The orbital elements of 360 meteors were reduced in the short trail program, and tabulated by Dr. Hawkins and Richard B. Southworth. The work will serve as a reference for future investigations of meteor dynamics, and has already formed the basis for a study of the statistics of meteor streams. Using a nonsubjective selection criterion, these authors found that 16 per cent of this sample belonged to major streams and 41 per cent to loose associations which they call minor streams. They concluded that, with sufficient data, the majority of meteors could be traced to a cometary origin.

The Harvard radio meteor project, under the direction of Drs. Whipple and Hawkins, and project engineer E. Stuart Fergusson, continued its construction program. Radio echoes from meteors are now being obtained at the Long Branch Station in Havana, Illinois.

At the George R. Agassiz Station, Hector C. Ingrao, research engineer, has been in charge since the resignation of Dr. Miczaika.

A spectrograph for the Cassegrain focus of the 61-inch is under construction at Boller and Chivens, Inc., and should be completed this year. A newly designed observing platform will allow operation of the telescope at the Cassegrain focus from the north side, and a new Cassegrain mirror has been ordered from J. W. Fecker Company for delivery this fall.

The radio astronomy group continued work at the Station, under Dr. Lilley's direction. A three-level solid-state maser was constructed and is in daily operation on the 60-foot radio telescope. The maser has been converted to multichannel operation, which enables a significant increase in observing efficiency. The sensitivity of this equipment at 21 cm is unexcelled and permits the detection of many objects previously beyond the limit of radio telescopes. The research group has discovered about 50 new radio stars, and investigated the 21-cm hydrogen-line emission from galaxies. The National Science Foundation sponsors this project.

With continuing support of the Air Force Cambridge Research Center, Dr. Menzel supervised solar research activities of Harvard groups at the Observatory in Cambridge, at the Sacramento Peak Observatory in Sunspot, New Mexico, and at the Radio Astronomy Station in Fort Davis, Texas. Dr. Menzel and John G. Wolbach made a study of the fibrous or filamentary structure of solar prominences. Mr. Wolbach used Sacramento Peak prominence records to prepare two edited films for public showing; one features this filamentary structure.

Dr. Barbara Bell investigated relations between geomagnetic

activity and 580 major solar flares observed from 1937 through 1959, giving particular attention to the magnetic type and location of the flaring sunspot group. She found that a major flare occurring in association with a magnetically complex spot group is much more likely to be followed by a great geomagnetic storm than is a similar flare in a unipolar or simple bipolar group. Great-storm flares show the expected concentration toward the central regions of the solar disk, and also an unexpected concentration in the northern solar hemisphere. In the 23 years studied, northern spot groups produced 62 per cent of all observed major flares and 86 per cent of those flares which were followed within 3 days by a great geomagnetic storm. This north predominance of great-storm flares appears about equally in each of the three sunspot maxima covered, and apparently is not related to the 11- or 22-year solar cycle.

Lowell R. Doherty, working with Dr. Menzel, investigated problems of the solar atmosphere and corona. They found that Lyman-α line absorption contributes strongly to the opacity of the atmosphere, and exceeds the absorption by atomic hydrogen and the negative hydrogen ion in the spectral region between the Lyman limit and approximately 2000A.

At Sacramento Peak, the Harvard solar project carried on its intensive patrol of active solar phenomena. Solar activity has remained at a high level, two years beyond the maximum of the current sunspot cycle.

George K. Schnable designed a K-camera that has been constructed and mounted on the 26-foot spar. This instrument, a white light photoheliograph, with a 70A passband centered near 3950A, will fill an important need in the program at Sacramento Peak by providing high-resolution photographs of the continuum radiation of flares, sunspots, plages, and granulation.

Dr. Elske v. P. Smith added to her observations and analysis of Balmer lines in the chromosphere and of ionized calcium lines in plages. She extended her digital computer program for automatic reduction of spectro-photometric data. Donald Carson made an intensive study of high-speed flare patrol films, and

began a comprehensive study of the relation between day-time seeing and environmental temperatures. Howard DeMastus, with Marion Wood of the National Bureau of Standards, examined notable cases of radio fadeouts that occurred in the absence of observed flares. William Booton prepared a number of pictorial displays of unusual solar phenomena observed by the project; a unique compilation showing the morphology of 200 limb flares is included.

Dr. Alan Maxwell remained in charge of the Radio Astronomy Station at Fort Davis, Texas. This station has now maintained continuous spectral radio observations of the sun since October, 1956; the records provide a comprehensive record of solar activity over that period. The station is thus able to supply information about various solar events to research organizations throughout the world.

A sweep-frequency receiver operating in the range 2.1–3.9 KMc/s was put into routine operation in February. This receiver uses one of the new backward-wave oscillators, and increases the frequency range of the solar spectrum analyzer to 5.5 octaves: 25–580 Mc/s, 2.1–3.9 KMc/s. A number of solar bursts have been recorded over this entire range.

Preparations have begun at the station for the procurement and installation by the Air Force of an 85-foot radio telescope, which should be in operation about May, 1961. Initially, about 60 per cent of the observing time will be devoted to solar radio emissions, while the remainder of the time will be spent on non-solar projects.

The relation of solar radio bursts to cosmic rays has been examined in some detail. The studies comprise both the modulation of galactic cosmic rays by the magnetic fields pervading the interplanetary plasma, and the low-energy cosmic rays emitted from the sun. The spectacular continuum (type IV) outbursts, believed to be generated by a synchrotron process in the solar atmosphere, have been shown to be closely related to the emission of low-energy cosmic rays from the sun. These cosmic rays

impinge on the earth's atmosphere about one hour after the initial flare on the solar disk.

We acknowledge with thanks various gifts and additions to funds from the following: American Philosophical Society, Dr. Barbara Bell, Mrs. Ralph Damon, Thomas C. Desmond, Mrs. Helen B. Gring, Paul Hammond, Higgins Trust, William S. Lindsley, Research Corporation, Sloan Foundation, John G. Wolbach, and an anonymous gift. These contributions have helped support major scientific investigations.

A bibliography of Observatory reports and publications issued during 1959–1960 is available on request from the Librarian, Harvard College Observatory, Cambridge 38, Mass.

Donald H. Menzel
Director

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